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Sown Biodiverse Permanent Pastures Rich in Legumes as an Adaptation Tool against Climate Change

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‘Historically, science has pursued a premise that Nature can be understood fully, its future predicted precisely, and its behavior controlled at will. However, emerging knowledge indicates that the nature of Earth and biological systems transcends the limits of science, questioning the premise of knowing, prediction, and control. This knowledge has led to the recognition that, for civilized human survival, technological society has to adapt to the constraints of these systems’

Nari Narasimhan (2007)

Acknowledgment

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Abstract

The semiarid region of Portugal has been showing a decrease of pastures productivity, caused by the worsening of the desertification process, promoted by climate change. Adaptation emerges as potential solution to increase the ecosystems adaptation capacity and reduce its vulnerability to climate change impacts. The main objective of this dissertation was to study the potential use of sown biodiverse pastures rich in legumes as an adaptation measure. The benefits of these pastures, specially, regarding carbon sequestration, are well documented, so we decided to study the effects of different types of soils and precipitation regimes in these pastures productivity. To perform this study, we compared the biodiverse pastures with most commonly used pastures in Alentejo, the natural pastures, by using the Normalized Difference Vegetation Index (NDVI). Our results showed no significant differences in productivity between natural pastures and biodiverse pastures. The biodiverse pastures showed low productivity in the Lithosols, when, compared with the natural pastures. As for the Cambisols and Luvisols, the biodiverse pastures productivity was a higher the natural pastures productivity. When comparing with the pastures that existed previously, the biodiverse pastures had lower densities in the Cambisols. Under dry conditions the biodiverse pastures registered low densities, when compared with the natural and previous pastures. The main consideration we can undertake with this study is, the biodiverse pastures did not improve the productivity as expected, and, in some cases, it reduced the system´s productivity. Our results showed that the biodiverse pastures productivity was higher when the climatic and soil conditions were more suitable for vegetative growth. So, when considering productivity, we cannot state that these pastures would be a good adaptation measure against climate change. Complementation with quality studies, e.g. soil moisture content and soil fauna richness, should be consider in future studies regarding this subject.

Keywords: precipitation, biodiversity, adaptation, climate change, Montado, Mediterranean basin, semiarid

Resumo

O aquecimento global é problema atual da sociedade moderna. Desde o inicio da industrialização que a concentração de dióxido carbono na atmosfera tem aumentado, o que, consequentemente, tem levado a um aumento da temperatura média global (0.6±0.2ºC). Uma das principais consequências do aquecimento global é a alteração dos padrões normais do clima.

O aumento da temperatura média e alteração dos padrões normais de precipitação, promovidos pelas alterações climáticas trarão inúmeros problemas naturais e socioeconómicos. A nível natural potenciará a perda e/ou fragmentação de habitats, erosão do solo, extinção e extirpação de espécies vulneráveis, dispersão de pragas, espécies invasoras e doenças, e afetará negativamente a fenologia de algumas espécies. A nível socioeconómico, os impactos negativos serão fortemente sentidos a nível de produção agrícola, segurança alimentar, recursos hídricos e energéticos, saúde pública, e turismo. Algumas regiões serão mais afetadas que outras, agravando as diferenças sociais e intensificando a degradação ambiental

Segundos dados mais recentes (Füssel & Jol, 2012), o continente europeu tem registado nas últimas décadas um aumento contínuo da temperatura média anual e diminuição da precipitação média anual. De todas as regiões europeias, a Bacia do Mediterrâneo será a mais fortemente atingida por estas mudanças dos padrões climáticos.

Os ecossistemas mediterrânicos são caracterizados pelo seu clima altamente variável, sendo frio e húmido, no inverno; e quente e seco, no verão. Uma elevada percentagem da precipitação anual ocorre nos meses mais frios, podendo ocorrer episódios de longas secas durante os meses mais quentes. Estes ecossistemas apresentam uma enorme riqueza específica, com 39 1000 espécies plantas vasculares, constituindo cerca de 12% das espécies mundiais (Kew, 2016); e 770 espécies de vertebrados (Myers *et al*, 2000).

Em Portugal, a região semiárida do Alentejo tem sentido, de forma mais severa, o aumento da temperatura média anual e diminuição da precipitação anual, verificado nos últimos anos. Esta região tem um historial de ordenamento do território desapropriado, más práticas agrícolas e o abandono de áreas agrícolas é uma realidade. Os impactos ambientais promovidos por este historial em conjunto com as alterações climáticas têm contribuído para a expansão da região semiárida e o agravamento do processo de desertificação que se tem verificado.

O Montado, um habitat característico da região Sul de Portugal, tem nos últimos anos registado um aumento da taxa de mortalidade do sobreiro e da azinheira. Adicionando a este problema, a taxa de renovação tem diminuído, levando à redução da densidade arbórea. Este ecossistema é caracterizado pela sua estrutura tipo-savana, de baixa densidade arbórea, normalmente Sobreiro (*Quercus suber*) e/ou Azinheira (*Quercus ilex L. subsp. rotundifolia (Lam.)*), e um sub-coberto composto por pastagens naturais e/ou culturas agrícolas. O Montado apresenta uma elevada importância económica e ecológica. A nível económico, a produção de cortiça e a exploração do gado, para a produção de carne, entres outros, são os principais produtos exportados, têm uma elevada importância na economia para o país. Ecologicamente falando, o Montado contribui fortemente na regulação do ciclo de água, no sequestro de carbono, proteção do solo contra os processos erosivos e, claro, hotspot de biodiversidade. Um historial de incorretos processos de exploração agrícola, somado ao abandono de áreas agrícolas, desflorestação, e a occorrência de pragas têm contribuído para o declínio do Montado. As alterações climáticas têm auxiliado no aumento do declínio do Montado.

Porquê adaptação? A aplicação de medidas de adaptação tem como principal intuito diminuir o grau de vulnerabilidade do ecossistema às alterações climáticas, aumentando a capacidade de adaptação do ecossistema. Desta forma, as medidas de adaptação reduzem os potenciais impactos negativos e aumentam os potencias impactos positivos das alterações climáticas.

A opção de estudar as Pastagens Permanentes Semeadas Biodiversas ricas em Leguminosas (PPSBRL), reside no facto de alguns estudos realizados salientarem a sua importância económica e ecológica como uma medida mitigadora no combate às alterações climáticas. Portanto, decidimos analisar a capacidade adaptativa destas pastagens biodiversas, de forma a avaliar o seu potencial uso como medida de adaptação às alterações climáticas

PPSBRL são um sistema de pastagens com elevado grau de diversidade de sementes, até 20 espécies ou variedades, permitindo a este sistema adaptar-se às variações das variáveis climáticas e a diferentes tipos de solo. Este facto permite que as pastagens biodiversas possam produzir mais matéria seca que as pastagens naturais. A presença de leguminosas assume um papel importante neste sistema de pastagens, visto que a simbiose com bactérias do género *Rhizobium* permite a fixação do azoto atmosférico no solo, tornando acessível este recurso a outras espécies vegetais. A fixação de azoto atmosférico permite que o sistema seja autossuficiente, reduzindo, assim, a necessidade de recorrer a adubos azotados e, consequentemente, as emissões de gases de efeito de estufa inerentes á criação dos adubos. A produtividade das leguminosas depende da presença de fósforo no solo, portanto é necessário adicionar este nutriente durante a implementação das pastagens biodiversas.

A elevada produtividade de matéria seca permite a produção de mais alimento para alimentação do gado, com menores custos, e o aumento da quantidade de matéria orgânica disponível no solo. A presença de matéria orgânica no solo é de extrema importância, visto que reduz o grau de erodibilidade do solo, aumentando a capacidade de retenção de água no sistema, e torna o solo mais rico em nutrientes e, consequentemente, mais fértil.

O objetivo desta dissertação será, então, avaliar as variações de produtividade das pastagens biodiversidade de acordo com variáveis climáticas e tipos de solo; e o potencial das pastagens permanentes biodiversas ricas em leguminosas como medida de adaptação às alterações climáticas no Alentejo.

O estudo realizou-se no Baixo Alentejo, mais propriamente em Mértola e Beja, usando imagens de satélite (Landsat 8, 7 e 5), num período de 8 anos. Optou-se por comparar as pastagens biodiversas com as pastagens naturais existentes na sua periferia e com pastagens que existiriam previamente à implementação das pastagens biodiversas. Como medida quantitativa para a comparação entre pastagens optou-se pelo uso do Índice de Vegetação de Diferença Normalizada (NDVI), uma ferramenta muito utilizada na avaliação da densidade do coberto vegetal. Na análise do NDVI procedeu-se à comparação sazonal das pastagens, e criação de rácios para as pastagens biodiversas e anteriores (previous) de forma a anular o erro criado pela comparação pastagens em solos muito diferentes. Visto que o rácio permite comparar duas grandezas, o seu uso permitiu-nos testar se as variações observadas estariam relacionadas com o tipo de solo (Cambissolos Eutricos, Litossolos Eutricos e Luvissolos) ou com a variação anual de quantidade de precipitação (anos secos e húmidos).

Numa comparação sazonal, verificamos que nas estações do ano onde o nível de precipitação é elevado, nomeadamente durante o Inverno e a Primavera, a produtividade entre as pastagens era muito semelhante. Na estação onde surgem as primeiras chuvas de outono, a produtividade das biodiversas apresentou valores de rácios inferiores ao das pastagens naturais e pastagens anteriores à implementação.

Os nossos resultados mostraram uma baixa diferença a nível de produtividade entre as pastagens biodiversas e as pastagens naturais. Ao comparar as biodiversas com as pastagens que existiam anteriormente à implementação das pastagens biodiversas, verificou se que, no global, não houve diferença significativa de produtividade. Reduzindo as nossas análises a nível local pudemos verificar algumas diferenças. Em Beja, as pastagens biodiversas tiveram ratios inferiores aos das pastagens que existiam previamente, o que significa que houve uma redução da produtividade local com a implementação destas pastagens. Curiosamente, o oposto foi verificado em Mértola.

Ao fazermos esta comparação em diferentes tipos de solo foi notório algumas diferenças. As pastagens biodiversas encontradas em Cambissolos, solos muito produtivos, tiveram baixa produtividade, quando comparadas com as pastagens anteriores, e a densidade da vegetação muito semelhante às pastagens naturais. Nos Litossolos, solos rasos e de baixa retenção, as produtividades de ambas pastagens foram inferiores ao das pastagens naturais, mostrando uma baixa produtividade destas pastagens neste tipo de solos. Isto poderá estar relacionado com a má produtividade das leguminosas em condições de stress hídrico. Finalmente, nos Luvissolos, solos limitados em C e N, a produtividade das pastagens biodiversas e anteriores foi superior às das pastagens naturais, com as biodiversas apresentando a maior produtividade das três. Isto demonstra que, de facto, a implementação das pastagens biodiversas em solos limitados em C e N, aumenta a produtividade do sistema.

Em situações de baixa precipitação anual, as pastagens biodiversas mostram baixos rácios de NDVI, indicando uma fraca produtividade quando comparados com as pastagens que existiam anteriormente. A produtividade obtida pelas pastagens biodiversas era, inclusive, inferior à produtividade normal das pastagens naturais. Em condições de excesso de precipitação, as pastagens biodiversas mostram uma melhor produtividade quando comparada com estas duas pastagens.

O nosso estudo demonstrou que, ao contrário do expectado, as pastagens biodiversas não tiveram uma produtividade superior à das pastagens naturais, e que em anos de escassez de água, estas pastagens não seriam uma boa opção como medida de adaptação. Mas em solos onde existe carência de matéria orgânica, estas pastagens têm, de facto, capacidade para aumentar a produtividade do sistema. Apesar da elevada biodiversidade característica destas pastagens, o facto é que a sua produtividade nunca foi muito superior à das pastagens naturais, e, inclusive, em solos com muitas limitações ao crescimento, e.g. Litossolos.

Palavras-chave: precipitação, biodiversidade, adaptação, alterações climáticas, Montado, Bacia Mediterrânica, semiárido

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List of Abbreviations

BASE - Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe

Biodiverse pastures – Sown Biodiverse Permanent Pastures rich in Legumes

CO_2 – Carbon dioxide

ENAAC - Estratégia Nacional de Adaptação à Alterações Climáticas

GEE – Greenhouse Effects

IPCC - Intergovernmental Panel on Climate Change

N – Nitrogen

Natural Pastures – Natural Grasslands

NDVI - Normalized Difference Vegetation Index

Previous Pastures – Pastures that existed before the implementation of the biodiverse pastures

RCP – Representative Concentration Pathway

SBPPRL - Sown Biodiverse Permanent Pastures rich in Legumes

Chapter 1 - Introduction

1.1 Global Warming and Climate Change

Climate change is the result of the Global Warming phenomena (Change, 1998), and it is starting to become a worldwide problem. This phenomenon is starting to become increasingly evident, as the global average air and ocean temperatures continue to increase; in some areas of the globe that are covered by snow and ice, the ice is melting in an unprecedented way, leading to sea level rise (Figure 1.1) (IPCC, 2007a).

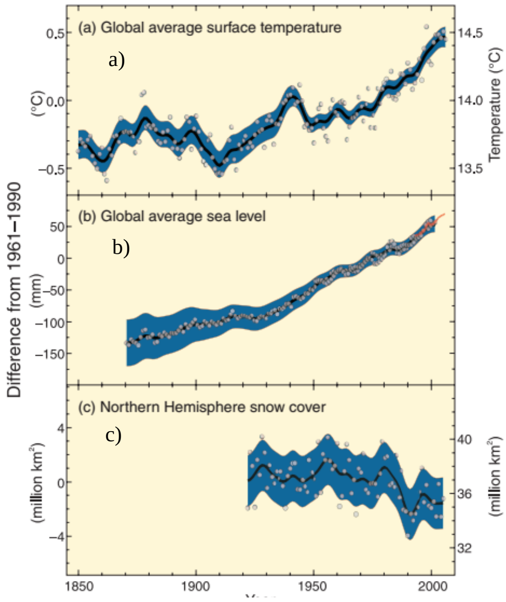


Figure 1.1 Representation of the changes in a) global average surface temperature, b) global average sea level and c) Northern hemisphere snow cover between March and April. The differences correspond to averages from the period 1961-1990. The smooth curves show decadal averaged values and the circles, the yearly values. Uncertain intervals are represented as the shaded areas, which are estimated from a comprehensive analysis of the known uncertainties a) and b) and from the time series c). (IPCC, 2007a)

Climate observations show us that since 1900, the average global temperature has increased 0.8ºC and the 12 hottest years observed globally since 1880 all occurred between 1990 and 2005 (UNFCCC, 2007). Recent projections from the Intergovernmental Panel on Climate Change (IPCC), regarding the increase in average temperature, stated that the expectable increases are predictable to be 0.3ºC (RCP 2.6) and 4.8ºC in the more severe projections IPCC 2014. However, at this point, it seems unrealistic to constrain climate warming to the least severe scenarios, as the barriers of 1.5 degrees warming at the end of the century seem to be already exceeded (Rogelj *et al.*, 2016). Hence, the main focus is to keep the rise of global temperature from surpassing the 2ºC (UNFCCC, 2011).

The Global Warming is a consequence of the increase of carbon dioxide (CO_2), methane (CH4) and nitrous oxide (N_2O) concentration in the atmosphere. The increase of greenhouse gases is mainly due to the high dependence on fossil fuels energy, like petroleum, coal, and natural gas. Added to this, the increase deforestation activities; the practice of intensive agriculture activities (Figure 1.2) (IPCC, 2007a; Füssel & Jol, 2012; de Melo Teixeira, 2010), the emissions from livestock; and changes in land use and management have also a great contribution in the increase of greenhouse gases (de Melo Teixeira, 2010).

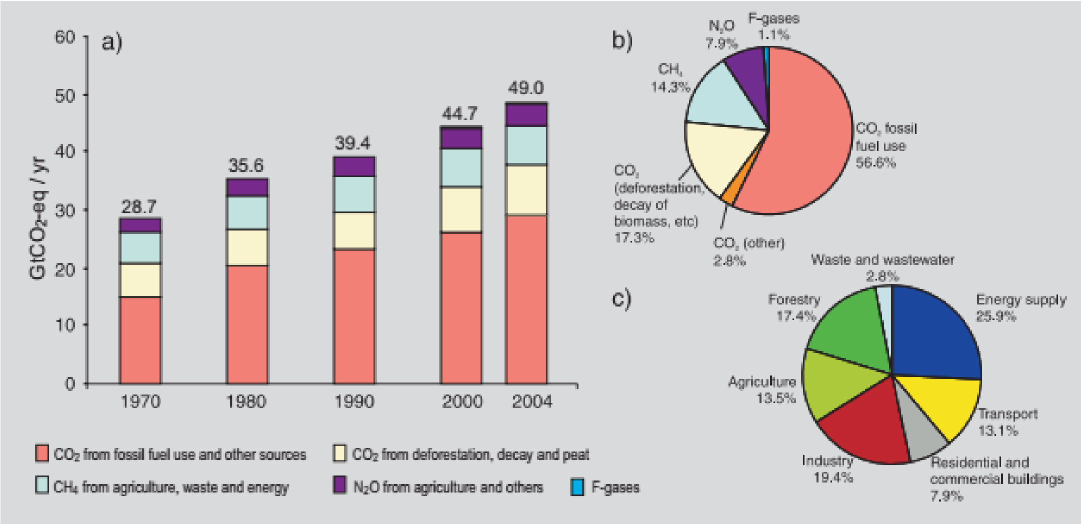


Figure 1.2 - Greenhouse Gases sources (IPCC, 2007a)

Soils are an important carbon storage unit for terrestrial carbon, accumulating carbon at a higher rate in grasslands, and forests; and at a smaller rate in croplands. So, whenever there are changes in land use, like shifts between forestry and agriculture, that affects the stability of the soil, there is an increase of greenhouse gases emissions into the atmosphere (de Melo Teixeira, 2010).

Environmentally speaking, climate change will, no doubly, lead to changes in precipitation patterns, increases of habitat loss and fragmentation, and soil erosion. In a biotic level, the most predictable impacts will be the occurrence of extinctions and extirpations of vulnerable species; the increase of diseases and plagues dispersal; shifts in species distributions; decoupling of coevolved interactions; increase of invasive or non-native species spreading; rise of species competitors; and the decrease of species survival and fecundity (Smith *et al.*, 2001; Kurukulasuriya & Rosenthal, 2003; Mawdsley *et al.*, 2009, UNFCCC, 2011).

In the socio-economical sector, the impacts will be greatly felt in agriculture production, food security, water resources (UNFCC, 2011), public health, energy resources, urban zones, tourism activity, and insurance (Santos & Miranda, 2006; Füssel & Jol, 2012; Luedeling *et al.*, 2013). Socially speaking, climate change will difficult the sustainable development of some regions, aggravate poverty, cause environmental degradation, and increase profound development inequality (UNFCC, 2011).

1.2 The Mediterranean Basin

Since the beginning of the XX century, the global average temperature has increased from 0.6±0.2ºC, with the European continent having one of the highest increases, registering 0.95ºC (Santos & Miranda, 2006). The winter temperature had a higher rise of change, when comparing with summer, and the areas with the highest values registered were The Norwest Federation of Russia and The Iberian Peninsula (Santos & Miranda, 2006; Füssel & Jol, 2012). Average temperature between pre-industrial and the decade 2002-2011 showed an increase of 1.3ºC, much more than the 0.8ºC. registered for the global temperature (Füssel & Jol, 2012).

The Figure 1.3, summarizes the observed and predicted impacts in the main regions of Europe.

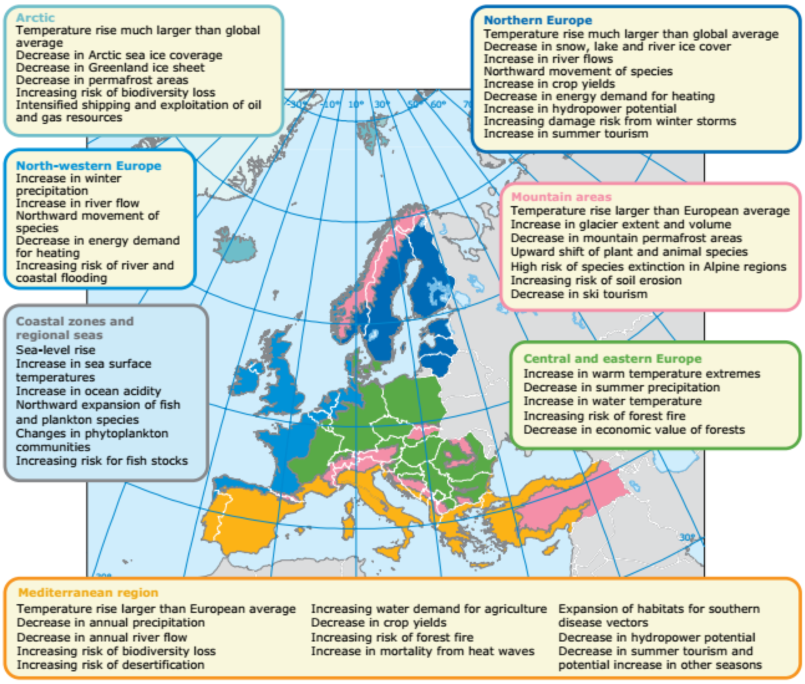


Figure 1.3 - Observed and projected impacts for Europe (Füssel & Jol, 2012)

According with recent climate change scenario projections, it is predictable an increase in temperatures nearly 2ºC in Ireland and the UK, more than 3ºC in central Europe and between 4 and 5ºC in the northern Boreal and some regions of the Mediterranean, by 2100 (IPCC, 2007). At the same year, atmospheric CO_2 concentration is expected to increase to at least 486 ppm, with the probability of going beyond 1000 ppm, a value that is higher than the 280ppm concentration registered in pre-industrial times (Lindner *et al.*, 2010).

The Climate change impact will differ from location, as a reflection of the variety of Bioclimatic zones (Figure 1.4) found in Europe. Regions more dependent on water availability, Temperate and Mediterranean ecosystems, will be negatively affected, with reduction of water availability, temperature increase, and rise of drought events (IPCC 2007a; Lindner *et al.*, 2010)

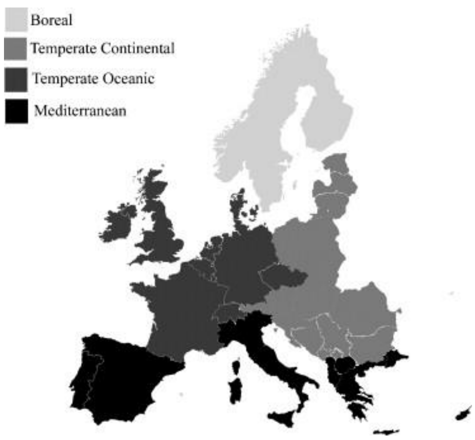


Figure 1.4- Europe's different bioclimatic zones (Lindner *et al.*, 2010)

In Southern Europe, climate change is projected to worsen the already stressful conditions of this region (IPCC, 2007a). In fact, the Mediterranean Basin has been suffering, in recent years, an increase of temperature and a decrease of precipitation, and, as consequence of climate change, this reality is expected to aggravate in the future (Füssel & Jol, 2012).

The Mediterranean climate is characterized by having cold and wet winters (Hobbs *et al.*, 1995; Rundel, 1998), with low solar irradiance (Hobbs *et al.*, 1995); and during the summer it shifts to a hot and dry weather (Hobbs *et al.*, 1995; Rundel, 1998), with high solar irradiance (Hobbs *et al.*, 1995). Nearly 90% of annual precipitation happens in the six cool months, and periods of extended summer drought can occur (Rundel, 1998). Figure 1.5 represents the global distribution of Mediterranean climate.

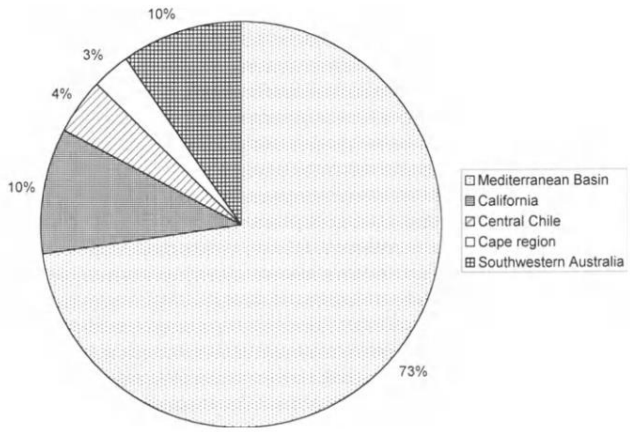


Figure 1.5 - Global distribution of Mediterranean climate. The chart shows that the Mediterranean Basin possesses the larger area of this climate (Cowling *et al.* 1996)

The ecosystems occurring within the Mediterranean climate have a large diversity of vascular plants, including 39.1000 plant species, which englobes nearly 12% of the world´s total vascular plants (Kew, 2016). The Mediterranean Basin has 25.000 species of the Mediterranean total (Cowling *et al.* 1996), making it one of the 25 Global Biodiversity Hotspots (Myers *et al.*, 2000; Cuttelod *et al.*, 2008) and one of the most important region for protection. According with Myers *et al.* (2000) the Mediterranean habitats represent 5 of the 25 biodiversity hotspots in the world, being the tropics the larger representative, with 15. Besides the high richness of plant species, the Mediterranean Basin has a high diversity of vertebrate species, 770 species; and endemic species rate. From the endemic species, it was registered 13.000 plants and 235 vertebrates, which 47 are birds, 46 mammals, 110 reptiles, and 32 amphibians (Myers *et al*, 2000).

Table 1.1 - Plant species diversity and conservation status of Mediterranean regions. Adapted from Crowling *et al.*, (1996)

REGION	AREA ($10^6 KM^2$)	NATIVE FLORA	THREATENED TAXA	MAJOR THREATS
CALIFORNIA	0.32	4.300	718	Urbanization Agriculture
CENTRAL CHILE	0.14	2.400	(?)	Deforestation Grazing Agriculture
MEDITERRANEAN BASIN	**2.30**	**25.000**	**4251**	**Urbanization** **Deforestation** **Grazing** **Agriculture**
CAPE	0.09	8.550	1300	Invasive alien plants Agriculture Urbanization
SW AUSTRALIA	0.31	8.000	1451	Agriculture Deforestation Introduced Pathogens

The increase of the temperature and reduction of the amount of precipitation is expected to cause a decrease in water resources, leading, consequently, to the reduction of water availability, summer soil moisture and crop yields, and increasing, regionally, the demand for irrigation. Furthermore, it might lead to increases of drought and heat waves events (more consecutive dry days); biodiversity loss (e.g. habitat fragmentation, decline in species richness and increase in invasive species), frequency of forest fires, and soil degradation (i.e. low organic content and fertility, shallow depth, and high salinity and erosion rate), which in worst cases, may lead to desertification (Füssel & Jol, 2012). Also, the low water income and the increasing the energy demand is expected to affect, negatively, the hydropower. (IPCC, 2007b; Füssel & Jol, 2012). All this, plus the expected negative impacts on the tourism sector (Füssel & Jol, 2012), will, no doubly, affect, very negatively, the socio-economy of many countries.

The Alentejo region of southern Portugal is the region more susceptible to climate change, being expected a great reduction in annual precipitation and an increase in maximum temperatures for 2100 (Figure 1.6). The semi-arid drylands found in the Alentejo (Figure 1.7) are characterized by water scarcity, low precipitation rate and variability and poor soil productivity (Sala & Lauenroth, 1982; Nunes *et al*, 2013). According with the BASE report, there has been an increase of frequency of droughts, especially between the months of February and April, in Portugal and the Alentejo region (Vizinho *et al.*, 2016).

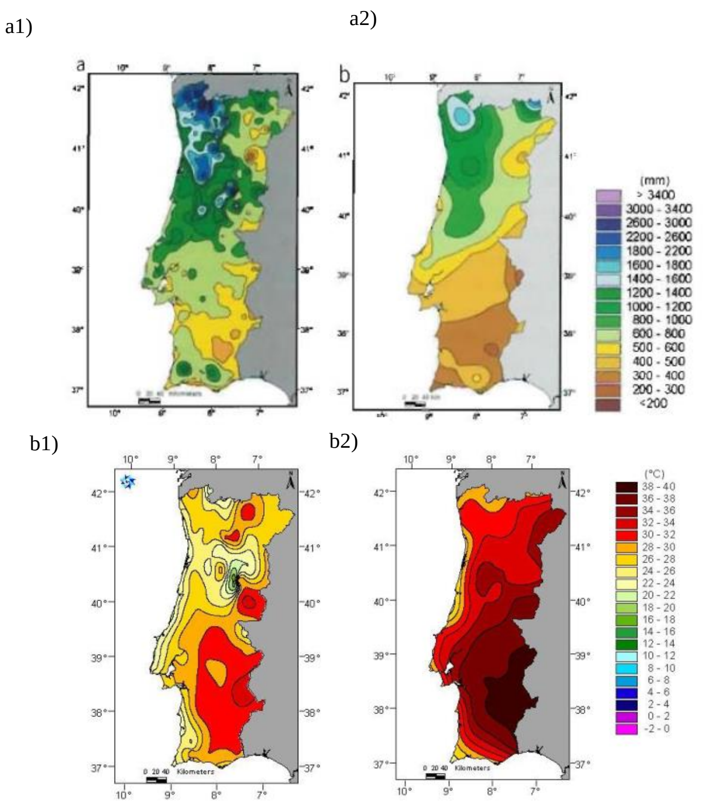


Figure 1.6 - The figures a1) represent annual Mean Precipitation observed between 1960 - 1990 and a2) the expected Annual Mean Precipitation for 2100 – GGA2 scenario by the Model Hadrm3. The b1) represents the Maximum temperatures observed between 1960 – 1990, and the b2) the expected maximum temperatures for 2100 – scenario A2 (Santos & Miranda, 2006)

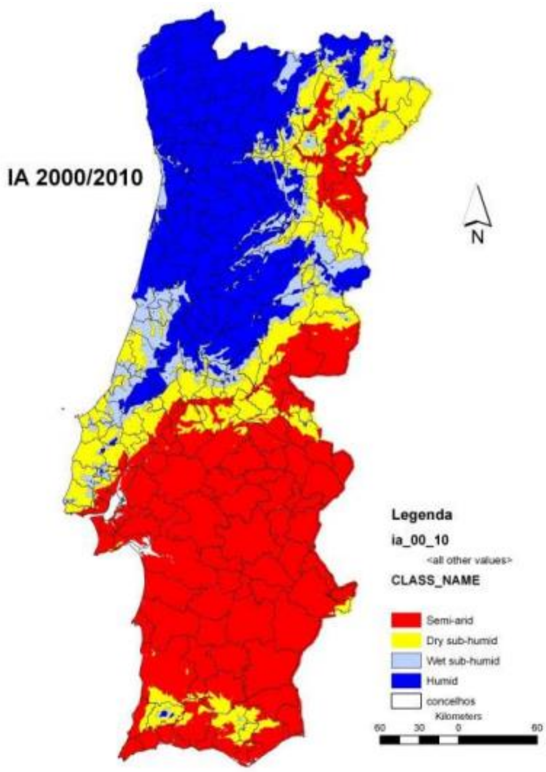


Figure 1.7 – Aridity Index for Portugal (2000-2010). This index is important to identify areas susceptible to desertification (do Rosário, 2014).

1.3. Desertification and Decline of Portuguese Montado

The *Montado* or *Dehesa*, in Spain, is a human-engineered ecosystem with an artificial structure, savanna-like forest, with perennial natural pastures and low density of evergreen oak woodland (Súrova & Pinto-Correia, 2008; Teixeira *et al.*, 2015; Vizinho, 2016). A diverse understorey vegetation characterizes this system, capable of mimicking Mediterranean grasslands, dominated by C3 annual plant species (Jongen *et al.*, 2014; Vizinho, 2015) and the presence of cork oak [*Quercus suber*] and/or holm oaks [*Quercus ilex* L. subsp. *rotundifolia* (Lam.)] (Figure 1.8) (Pinto-Correia, 1993; Coelho & Leitão, 2013; Pinto-Correia & Mira Potes, 2013; Teixeira *et al.*, 2015; Vizinho, 2015). Other species of *Quercus spp.* can also be found in the Montado, as the *Quercus faginea* and *Quercus pyrenaica* (Pinto-Correia & Mira Potes, 2013). The *Quercus spp.* can be sometimes associated with other tree species, like maritime pine (*Pinus pinaster*), and stone pine (*Pinus pinea*) (Coelho & Leitão, 2013; Pinto-Correia & Mira Potes, 2013).

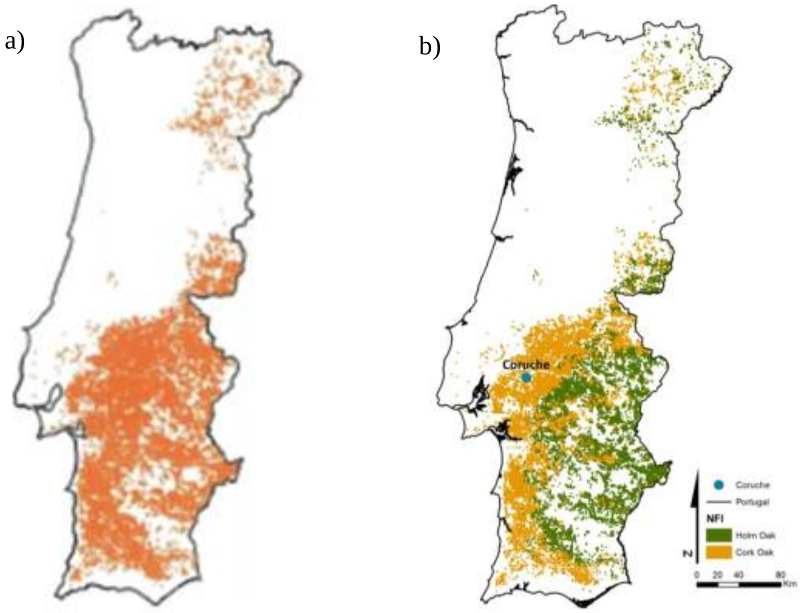


Figure 1.8 - a) Montado distribution (Vizinho, 2015) and b) Holm Oak (Green) and Cork Oak (Yellow) distributions in Portugal (Crous-Duran, *et al.*, 2014)

The Montado is highly dependent on human management to maintain their biodiversity and ecosystem services, being ecologically unsustainable without it (Caetano, 2007; Correia, 2014; Vizinho, 2015).

In South of Portugal, the increase of soil degradation and desertification has been a current problem through the years (Sequeira, 2012). Desertification is referred when an ecosystem suffers land degradation and, consequently, loses its capacity to provide ecosystem services (Costantini *et al.*, 2016). The main catalysts found were related to incorrect spatial planning, leading to irreversible soil destruction; bad agrarian technology application; depopulation of the interior (Sequeira, 2012; Vizinho *et al.*, 2016); and changes in climate patterns (Table 1.2) (Puigdefábregas & Mendizaba, 1998; Sequeira, 2012). If nothing is made to reverse this process, the ecosystem´s loss of structure and functionality can become irreversible (Costantini *et al.*, 2016).

Table 1.2 - Observed changes in temperature, precipitation, and extreme events in Alentejo. Adapted from ENAAC, 2013a

	Temperature		**Precipitation**			**Drought**
Region	Variability in mean annual temperature (since 1976)	Anomalies in summer mean temperatures (1960-90 as reference)	Annual mean Precipitation (1960-90 as reference)	Seasonal variation		
				Spring	**Autumn**	
Alentejo	+0.044ºC per decade	5 hottest summers after 1990	Higher than average in 9 of the last 30 years. 55mm of annual lost	Systemic reduction. 50mm reduction in march, when compared with 1940-70 and 1970-2000	In 12 of the last 20 years, the amount of precipitation in autumn was higher than average	More frequent and severe drought episodes (since 1990)

The continuous increase of the semiarid climate in the South of Portugal, will lead to reductions of water superavit, annual water runoff and aquiferous recharge; an increase of extreme droughts and floods events (Sequeira, 2012); and, eventually, land degradation and disruption of local economies (Puigdefábregas & Mendizaba, 1998).

In addition, some studies have stated the occurrence decline of the Montado (Souza, 2012; Pinto-Correia & Mira Potes, 2013; Godinho *et al.*, 2016), specially the Holm oak Montado (Caetano, 2007; Pinto-Correia & Mira Potes, 2013). The Montado density and natural regeneration rate has been decreasing, and the mortality, in opposite, has been increasing (Pinto-Correia & Mira Potes, 2013), making this decline a very worrisome issue, threatening Montado and Cork oak woodlands stability and productivity (Caetano, 2007).

There is, yet, no specific cause for this decline. Instead, many authors consider it a combination of different factors (Sousa *et al.*, 2007; Da Clara & de Almeida Ribeiro, 2013). The factors can be divided as follows:

1. Predisposition factors - soil type, characteristics, and hydrological conditions. Soil erosion and reduction of organic matter and pH can lead to the disruption of the nutrient cycle, leading to soil acidification. The decrease of traditional agriculture practices to more intensive or extensive practices, which causes gradual reductions of cultivations and grazing, and the recolonization of the abandoned lands by shrubs, have made some areas more susceptible to fire risks (Pinto-Correia, 1993).
   Excess of debarking, pruning, shrub clearing and soil mobilization done improperly or out of time, can affect the phytosanitary state of the trees, making it more susceptible to stress. High density of shrub cover can be dangerous, since it limits the water availability to the rest of the system and increases fire probability. The rise of number of wildfires in Portugal has contributed to noticeable decline in Cork Oak and Holm Oak populations.
   Over grazing, by excessive headstocks, cause soil compaction, increase soil erosion and diminish the regeneration potential of the system (Caetano, 2007; Sousa *et al.*, 2007).

2. Induction factors – The main induction factor is the increase of summer temperature and, consequently, drought events (Caetano, 2007). Rotation between drought events and heavy rain has allowed the spreading of diseases, plagues and other agents, that amplified the impacts already caused by other stressful factors (Caetano, 2007; Sousa *et al.*, 2007).
3. Contribution factors - Diseases, plagues, and other agents (Caetano, 2007; Sousa *et al.*, 2007; Godinho *et al*, 2016). For example, *Phytophthora cinnamomi*in combination with other predisposing factors, reduce cork and holm oak trees resilience, increasing their susceptibility to other stress factors. (Sousa *et al.*, 2007; Da Clara & de Almeida Ribeiro, 2013);

1.4 What to do?

The southern region of Portugal aggregated potential negative impacts varies from medium to highest (Figure 1.9a), and its capacity to adapt is very low (Figure 1.9b). The adaptive capacity represented in Figure 1.9b relates to the population knowledge and/or awareness; economic and technological resources; and the infrastructures and institutions capacity to adapt to climate change (Füssel & Jol, 2012). The combination of these two characteristics makes Alentejo a high to medium potentially vulnerable region to climate change. Hence, it is necessary reduction of the negative impacts, amplify the positives ones and, at the same time, increase the adaptive capacity of the ecosystems.

For this, we need to apply specific measures that undertake the reduction of negative impacts, amplify the positives and, at the same time, increase the adaptive capacity of the ecosystems. With this, we ensure a reduction of vulnerability to climate change (IPCC, 2007b; Füssel & Jol, 2012). Adaptation is an important process, that allows us to benefit with positive impacts and reduce or minimize the negative impacts of Climate Change (IPCC, 2007b; Mawdsley *et al.*, 2009).

The IPCC (2007b) defines adaptation as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Seeing this duality of impacts, the application of adaptive measures and strategies needs the knowledge of the specific attributes of climate change that are likely to have impacts over species or habitats (Hulme, 2005). Adaptation is an essential mechanism in reducing the vulnerability of some ecosystems and species to climate, and should be seen as a complementary mechanism to the application of mitigation measures, since the latter alone would not be enough (Kurukulasuriya & Rosenthal, 2003).

In the context of ecosystem conservation and regeneration, adaptive strategies can be divided into four categories: land and water management and protection, direct species management, monitoring and planning, and policies and laws (Mawdsley *et al.*, 2009).

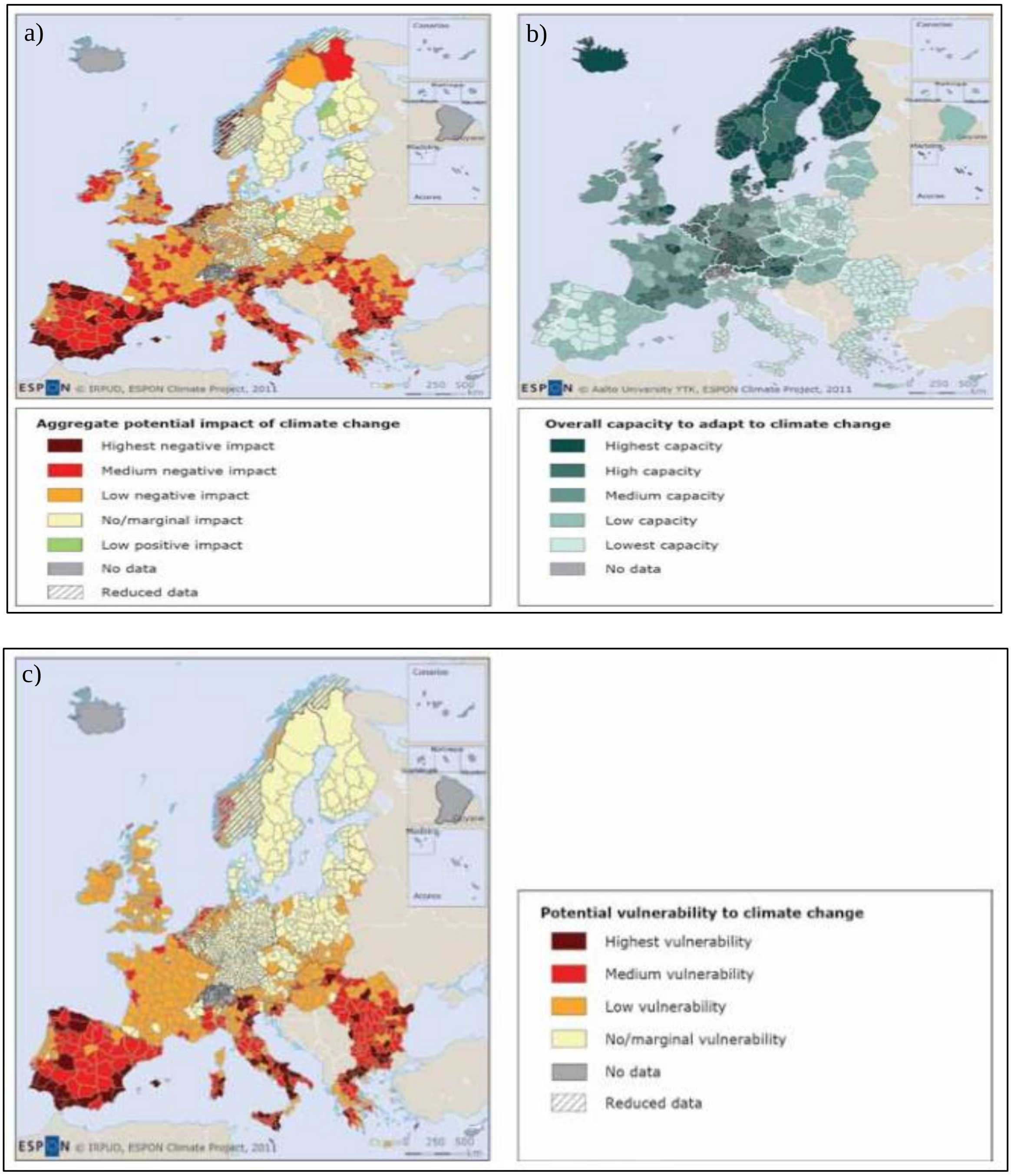


Figure 1.9 – Map a) represents the potential impacts of climate change in some areas, b) their capacity to adapt and c) the potential vulnerability to climate change. Map c) is obtain by combining the aggregate potential impact with the capacity to adapt to climate change (Füssel & Jol, 2012)

1.5 Why adapt?

As already pointed above, Montado is a rich biodiversity ecosystem, highly productive, that combines different types of land management, such as agriculture and forestry (Belo *et al.*, 2009; Pinto-Correia & Mira Potes, 2013; Correia, 2014; Vizinho, 2015; Teixeira *et al.*, 2015).

The presence of trees and grass affects ecosystem temperature, reducing temperature range, and water regime, dilating growth season. The under-cover plays a major role in the *Montado* sustainability and profitability, protecting the soil from erosion and its seedlings and contributing to the nutrients recycling

(Pinto-Correia & Mira Potes, 2013). The combination of tree cover, herbaceous species, animal grazing and the existence of shrub patches in the under-cover, creates a very particular landscape pattern, which reflects in a high diversity of vertical and horizontal vegetation structure, rarely found in other ecosystems (Pinto-Correia & Godinho, 2013; Pinto-Correia & Mira Potes, 2013).

In silviculture, the farmers extract the cork (Caetano, 2007; Reis & Calafate, 2014) from the trees for economically purposes. It is later transformed into stopper for wine, sparkling wine, and champagne bottles. The cork can also be used in other industries, like construction, doe to its insulating properties; and footwear (Reis & Calafate, 2014). The Iberian Peninsula has, nearly, 80% of cork production worldwide, being Portugal the biggest producer worldwide, with c.a. 13.000 to c.a. 18.000 tons per hectare. Portugal is also the first in the industrial transformation and commercialization sector (Caetano, 2007)

The exploitation of ruminant cattle, being the ovine the most abundant species, has the main objective of obtaining meat, wool and dairy products (Caetano, 2007; Reis & Calafate, 2014). The production of cereals was an important activity in the past, but has been losing importance in the last years, turning the *Montado* into a more sylvi-pastoril system (Súrova & Pinto-Correia, 2008; Pinto-Correia & Mira Potes, 2013; Pinto-Correia & Godinho, 2013).

Other land uses in this ecosystem include, hunting, mushroom collecting, rural and environmental tourism, bee-keeping for honey production recreation and leisure activities and support local identity (Caetano, 2007; Súrova & Pinto-Correia, 2008; Reis & Calafate, 2014; Correia, 2014).

Ecologically speaking, the *Montado* has a very important role in the systems water cycle regulation, carbon sequestration, soil erosion prevention, and, as reference previously, an important biodiversity hotspot. (Caetano, 2007; Pinto-Correia & Mira Potes, 2013; Reis & Calafate, 2014). The arboreal and herbaceous species have strong effects in the carbon and nutrient cycle, providing organic matter and, consequently, nutrients to the system. The biomass, from grass and trees, has a high carbon sink potential, enhancing soil stabilization and protection, and reducing ecosystem degradation. Cork oak *Montados* can sequestrate annually between 1 and more than 3 tons of carbon per hectare, but in Holm oak *Montados* the sequestration range is lower, less than 1 ton of carbon per hectare (Pinto-Correia & Mira Potes, 2013).

According with ENAAC report (ENAAC, 2013b), in continental Portugal, are expected until 2100 the increase of average annual temperature to 2.5ºC (RCP4.5) or 4ºC (RCP8.5); the number of annual tropical nights (nights with temperatures at 20ºC or more) to more than 20 nights in the south; and the number of days without precipitation, between 12 and 20. As for precipitation, reductions between 20% (RCP4.5) and 30% (RCP8.5) are expected in for all regions; and the occurrence of strong interdecadal oscillations.

These scenarios will have strong environmental and socio-economic impacts on the Montado ecosystem:

- Increase of dry matter production from pastures during the winter. In the beginning of march dry matter will decrease, leading to the increase usage of preserved foods for cattle feeding;
- Dry grass quality for summer consuming will decrease;
- The bush areas will increase in more arid regions, due to the increase of the dry season;
- The increase of episodes of heavy rainfall will cause the reduction of grazing time;
- Cattle mortality will increase, leading to a reduction productivity;

- The Increase cattle confinement will promote NH_3 and GEE emissions;
- Decrease of food availability, caused by crop loss;
- Increase susceptibility to plagues and diseases attacks, due to increase of environmental stress;
- Will affect negatively cork oak and holm oak regeneration and increase tree mortality;
- Reduce productivity in soils with low water retention;
- Increase soil erosion;
- Decrease biodiversity;
- Increase susceptibility to desertification (ENAAC, 2013b).

These potential impacts make the Montado very susceptible to climate change.

1.6 Sown Biodiverse Permanent Pastures Rich in Legumes as an adaptive measure?

Nearly 40% of earth´s terrestrial area, is covered by Grasslands (Jongen *et al.*, 2011). In Europe, they are important land use, covering more than a third of the continental agricultural area (Smit *et al.*, 2008). Portugal has nearly 1.8 million hectares of grasslands (Teixeira *et al*, 2011).

The grasslands are an important feed source for herbivores and ruminants; prevents soil erosion by giving slopes more stability; regulates water inflow and outflow from the system, and, also, purifying it from fertilizer and pesticides use; and is important habitat for biodiversity (Smit *et al.*, 2008). Furthermore, they have an important role on terrestrial carbon cycle, storing a large amount of carbon in the soil (de Melo Teixeira, 2010).

Grasslands are very sensitive to changes in climate patterns, specially, if those changes affect annual precipitation (Smit *et al.*, 2008; Jongen *et al.*, 2011). The increase of drought events may affect the grassland´s capacity to store carbon, reduce its productivity and impact the net ecosystem carbon exchange (Jongen *et al.*, 2011).

Grasslands from a Mediterranean ecosystem are very diverse, composed of grass species, annual plants, and herbaceous species (Smit *et al.*, 2008). The combination of C3 species and drought resistant perennials, allows a good adaptation to periods of water scarcity. Still, the ecosystem is vulnerable to reductions in precipitation amount, which limits the amount of water stored in the soil and available for use. The grasslands are active during the winter and early spring, and in May, the senescence process starts. So, changes in precipitation amount and seasonality have impact on grasslands respiration and productivity rates (Jongen *et al.*, 2011).

In Portugal, we can find a wide variety of grassland or pastures[1], varying from spontaneous to sown, being, more or less biodiverse, existing under rainfed or irrigated conditions, needing or not to be fertilized, and being located under three canopies or in areas with a high three dispersion. Considering only rainfed pastures, since they are the main focus of this thesis, we can divide them in the three major groups that exist in Portugal: spontaneous unfertilized pastures or natural pastures; spontaneous fertilized pastures or fertilized natural pastures; and sown biodiverse pastures (de Melo Teixeira, 2010).

[1]In terms of definition, the main difference between "pastures" and "grassland", is the first one englobes the presence of grasslands and the grazing activity, while the second one only considers the plants in its definition (de Melo Teixeira, 2010). To simplify the reading and the understanding, we considered these two synonyms.

The Grasslands are an important resource of goods and ecosystem services:

- Domestic livestock production;
- Seed beds with a lot of diversity;
- Habitats for a variety animal and plants;
- Carbon sink, storing approximately 34% of the global stock of carbon in terrestrial ecosystems;
- Soil protection against erosion and desertification;
- Tourism and recreation (Silva *et al.*, 2008)

The Natural Grasslands or just Natural Pastures are the most used grass system in Portugal, consisting of fallow stages from long cereal rotations, or spontaneous vegetation in previous croplands. These pastures are considerably poor in feedstock for the livestock and are, usually, associated with several environmental impacts. Besides the occasional shrub control, these pastures have no specific management procedures. The Fertilized Natural Pastures are natural pastures that are fertilized, being no different in species content and the same necessity for shrub control from the natural pastures, but varying in productivity (de Melo Teixeira, 2010).

The Sown Biodiverse pastures are based on the introduction of specific species or varieties in less diverse grasslands, with the aim of improving the ecosystem structure and function, creating complementary ecological niches, and increasing the systems overall productivity (Teixeira *et al.*, 2011). Many studies (Crespo, 2008; Teixeira *et al.*, 2008; Teixeira *et al.*, 2015), have documented the positive effects of applying the Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL) in Montado areas, with a special emphasis on its capacity to increase the ecosystems productivity. Hence, we decided to conduct a study of potential use of the biodiverse pastures as adaptive measure, by comparing productivity between natural pastures and biodiverse pastures, in different types of soils and precipitation variations.

1.6.1 What is SBPPRL?

The Sown Biodiverse Permanent Pastures rich in Legumes (SBPPRL) are a system of engineered pastures, created by Eng. David Crespo in the 70s, that uses a mixture of 20 or more species or varieties of seeds, containing legumes, grass, and other functional groups (Figure 1.10) (Rodrigues, 2008; Teixeira *et al.*, 2011). The SBPPRL are characterized by having a long-life span, varying between 10 to 25 years (reseeding needed every 10 years), and the presence of different species of legumes (inoculated with *Rhizobium*) with the capacity of capturing atmospheric nitrogen and making it available for the other species of the system (Crespo, 2008; Rodrigues, 2008; Teixeira *et al.*, 2011; Esteves, 2013). The grass-legumes system helps to maintain the equilibrium of nitrogen input and output in the system, (Rodrigues, 2008; Esteves, 2013), reducing the probability of leaching events (Rodrigues, 2008). The productivity of legumes depends on the presence of phosphorus in the soil, so these nutrient as to be added to the biodiverse pastures (Teixeira *et al.*, 2008a). In the first year, the cover percentage of legumes is normally 50 %, and has the possibility of increasing in the second and third year. As the pasture stabilizes, the percentage of grass increases and legume coverage starts decreasing, until it stabilizes between 25-30%, being the legume optimal range between 30-50% (Teixeira *et al.*, 2015).

Figure 1.10 - Sown Biodiverse Permanent Pastures Rich in Legumes (Teixeira, 2015)

The enormous variety and diversity of seeds, enables the system a higher edaphoclimatic adaptability, granting the system a higher possibility of surviving and adapting to the local conditions, like weather and soil, bringing a larger yield to the explorations (Rodrigues, 2008; Teixeira *et al.*, 2011; Esteves, 2013).

Each seed mixture is different and varies according with the area´s soil physical and chemical characteristics, and climatic conditions, where the biodiverse pastures are implemented (Teixeira *et al.*, 2011). The various mixtures may have some species in common (Teixeira *et al.*, 2011; Teixeira *et al.*,2015). The Table 1.3 shows the most common sown species that can be found in some mixtures.

Table 1.3 – Common sown species that can be found in some SBPPRL mixture. Adapted from Teixeira *et al.* (2015)

Self-reseeding annual legumes	*Trifolium subterraneum* (ssp. *subterraneum*, ssp. *brachycalycinum* and ssp. *yanninicum*), *T. michelianum*, *T. resupinatum*, *T. vesiculosum*, Ornithopus spp. (e.g., *O. sativus*, *O. compressus*), *Biserrula pelecinus* and annual Medicago spp. (*M. polymorpha*, *M. scutellata*, *M. truncatula*, *M. rugosa*, *M. litorallis*)
Drought resistant perennials with deep roots	*T. fragiferum, Onobrychis viciifolia, Hedysarum coronarium* and *Medicago sativa*
Summer dormant species	*Dactylis glomerata, Phalaris aquatica, Festuca arundinacea* and *Lolium perenne*
Annual grasses	*Lolium multiflorum,* and *L. rigidum*
Spontaneous plants (optional seeding)	*Plantago spp., Cichorium intybus, Vulpia spp.* and *Bromus spp*

1.6.2 Why SBPPRL?

In a study conducted in Alentejo by Vizinho (n.p), it was identified six adaptive strategies that are already being applied or that farmers want to start applying: 1) Rain water retention, 2) Diversity, 3) Species, 4) Microclimates, 5) Good management practices, and 6) Protection. Considering these five key strategies, we realized that the biodiverse pastures have an important role on rain water retention, diversity, species, and good management practices adaptation strategies. As mentioned previously, studies have showed that the application of biodiverse pastures have positive benefits on the system it is applied and allows it to use in a more efficient way all the available natural resources.

The presence of legumes allows the capture and dispersal, in the system, of nitrogen. The system becomes less dependable on nitrogen fertilizers and the fossil fuel emissions related with fertilizer is reduced (Crespo, 2008; Teixeira *et al.*, 2008; Esteves, 2013; Teixeira *et al.*, 2015). The presence of legumes also improves grass quality, by increasing the amount of protein available and the quality of cattle feeding. Hence, the legumes improve the soil fertility, making it less vulnerable to erosion, and increase grass production at a very low cost (Crespo, 2008; Teixeira *et al.*, 2015).

The biodiversity of theses pastures allows an increase of rainfed pastures persistence, due to the capacity of different species to adapt to certain soils characteristics. The variety of species precocity allows the system a greater resistance to hotter years or thinner soils. As for seasons with high intensity of precipitation or more depth soils, species with a higher life cycle can extend grass production through a longer time (Crespo, 2008). The introduction of a large amount of variety of Mediterranean species in poorer ecosystem could help improve the system productivity and make the ecological niches more stable (Esteves, 2013; Teixeira *et al.*, 2015).

SBPPRL has the capacity of improving a system´s productivity (Teixeira *et al.*, 2008a; Teixeira *et al.*, 2015). The captured CO_2 is stored in the soil in the form of labile organic matter by the pastures roots (Teixeira *et al.*, 2008a). The high density of renewal annual plants roots allows a high input of organic matter, in the form of soil organic carbon (SOC) (Rodrigues, 2008; Teixeira *et al.*, 2015). The SBPPRL can capture, nearly, 4.7 ton CO_2/year.ha, in the soil (Rodrigues, 2008). The organic matter can also be reintroduced in the system by livestock grazing and returning undigested fiber to the soil, and leaves senescence and decomposition (Teixeira *et al.*, 2008b; Teixeira *et al.*, 2015). The presence of organic matter allows an improvement in soil quality and resilience; increasing nutrient availability, improving plants productivity, enhancing water retention and water cycle, and reducing surface runoff and erosion (Teixeira *et al.*, 2008a; Rodrigues, 2008; Teixeira *et al.*, 2015). According with Teixeira *et al.* (2015), between 1990 and 2008, approximately 94.260 hectares of rainfed SBPPRL were installed in Portugal, which lead to an increase of soil organic matter (SOM) in these grasslands and, nearly, 3.5 million tons of CO2 were sequestered by SBPPRL as soil carbon.

In a study performed by Teixeira *et al.* (2015), the biodiverse pastures showed a great resilience to different environmental pressures, always keeping high levels of dry matter, when compared with semi-natural pastures. This fact can positively affect grasslands stability and be consider as an important adaptation measure against climate change.

These pastures also promote soil fauna biodiversity, having very positive effects on microorganisms, little arthropods, coprophages insects and earth worms (Teixeira *et al.*, 2008b).

1.7 How to study SBPPRL adaptive capacity?

We decided to study the SBPPRL adaptation capacity by using the Normalized Difference Vegetation Index (NDVI) as a measure of green biomass (Cramer & Hoffman, 2015). The NDVI is a tool widely used for vegetative studies, using the ratio of the difference between the red and near-infrared bands of the electromagnetic spectrum and their sum (Fensholt *et al.*, 2006; Huang *et al.*, 2013). The NDVI ratio varies between -1 to 1 (Fensholt *et al.*, 2006). The ratio properties allow the NDVI to silence a large proportion of the noise caused by innumerous variables, like: changing sun angles, topography, clouds or shadow, and atmospheric conditions (Matsushita *et al.*, 2007). It is a non-destructive, none invasive method of sampling, allowing, in well-managed grazing systems, a good indicator of pasture productivity (Flynn, 2006).

The index has strong relationship with the intercepted photosynthetically active radiation, leaf area index, and net primary production (NPP) (Lo Seen Chong *et al.*, 1992; Lu *et al.*, 2003; Huang *et al.*, 2013), allowing multiple application: a) Global change; b) Phenological changes; c) Crop growth; d) Monitoring and yield prediction; e) Drought and desertification monitoring; f) Wildfire assessment, and g) Climatic and biogeochemical modeling (Huang *et al.*, 2013);

The NDVI correlation with The Net Primary Productivity is very important for this study, allowing us to understand the changes in the rate of net production of organic matter by the vegetation, and, consequently, making it a good terrestrial vegetation activity describer (Lo Seen Chong *et al*, 1992).

When estimating vegetation parameters from the NDVI, it is important to take in mind the following aspects:

1. Developmental patterns from different plants across seasons or years (Phenology);
2. Variations on precipitation, radiation, temperature, and humidity;
3. Natural (fire, flood, and windstorms) and Anthropogenic (changes in land use and land management Disturbance events);
4. Satellites sensor conditions;
5. Contamination by clouds, aerosols, water vapor, and background soil color (Lu *et al.*, 2003);

All these aspects affect the information we can undertake from remote sensing and the application of the NDVI. Hence, it is important the elimination or reduction of the “noise” created by these aspects, by applying satellite calibration, orbital correction, detection and removal of atmospheric contamination, and image registration (Lu *et al.*, 2003).

1.8 Thesis Objective

The main goal of this thesis is to provide a new adaptive option for the desertification problem of Alentejo, as a consequence of Climate Change. We focused this work on studying the potential use of Sown Biodiverse Permanent Pastures Rich in Legumes as an adaptive measure against Climate Change. For that we:

- Compared the productivity (NDVI) of biodiverse pastures with that of natural pastures and pastures that existed in the same place, where the biodiverse pastures were implemented, in different years and seasons;
- Compared the productivity of the biodiverse pastures in different soil types, common on Baixo Alentejo.
- Verified the effect of precipitation variation in pastures productivity and compared them, so that we could understand the effect of changing climate on the different pastures.

Chapter 2 - Methodology and Materials

2.1. Characterization of study areas

2.1.1. Location

The studies areas exist in the semi-arid region of Alentejo and Baixo Alentejo sub-region (NUT III). The first study area was Mértola, a municipality with 1293 km^2 of area of and 9 parishes (Lecoq, 2000; Esteves, 2013). The second study area was Beja, an area with, approximately, 1 140.21 km^2; 35 854 habitants, and 18 parishes. Beja is one of the biggest municipals in Portugal. (CM Beja, 2016). In each study area, we chose different sites, in the Municipality of Mértola we chose Mértola and Alcaria Ruiva; and in Beja, we chose Pias, Pedrogão and Baleizão (Figure 2.1).

Figure 2.1 - Study Areas in Baixo Alentejo. a) Baleizão, b) Pedrógão, c) Pias, d) Alcaria Ruiva and e) Mértola

2.1.2. Climate

The Alentejo is located in the Southern region of Portugal, characterized by having Mediterranean climate with cold and humid winters, where most of the precipitation is concentrated between December and February (Casimiro, 1993; Vizinho *et al.*, 2016); and hot and dry summers, with elevated temperatures (>30ºC) and insolation, and scarce of precipitation events (Casimiro, 1993; Esteves, 2013; Vizinho *et al.*, 2016). Annual precipitation averages the 600 mm/year (Vizinho *et al.*, 2016). The Baixo Alentejo sub-region climate is classified, in the Köppen Classification, as a temperate climate, with hot and dry summers (Csa) (IPMA, 2016) (Figure 2.2).

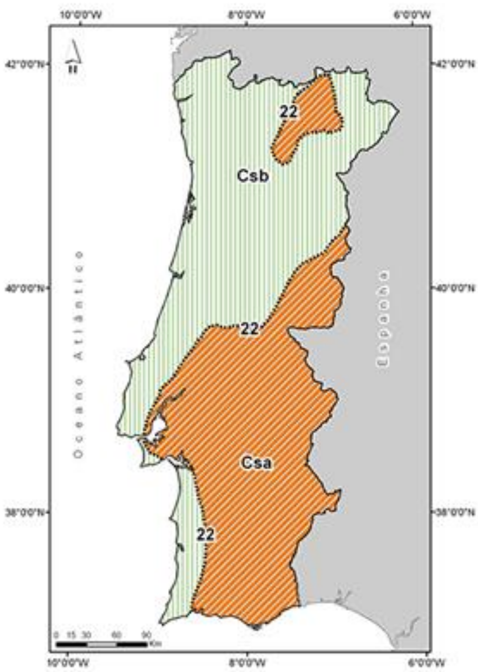
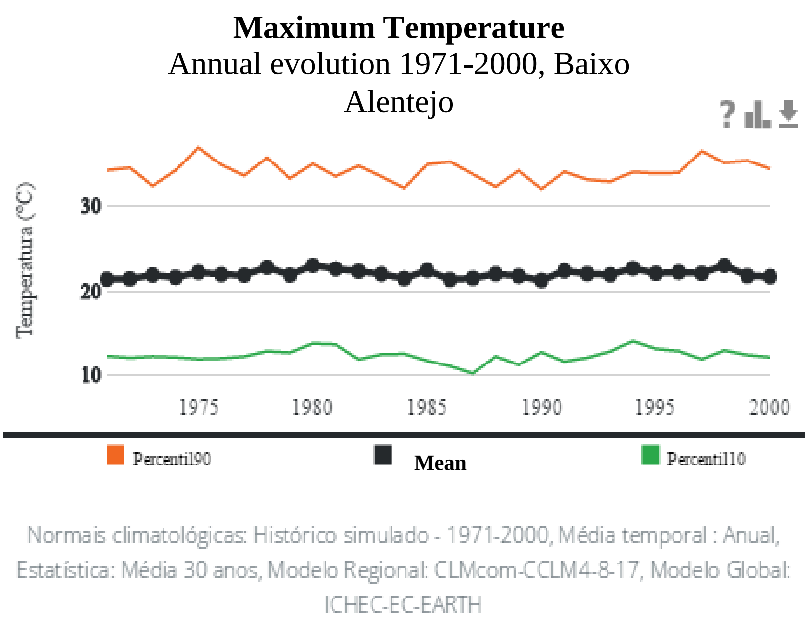
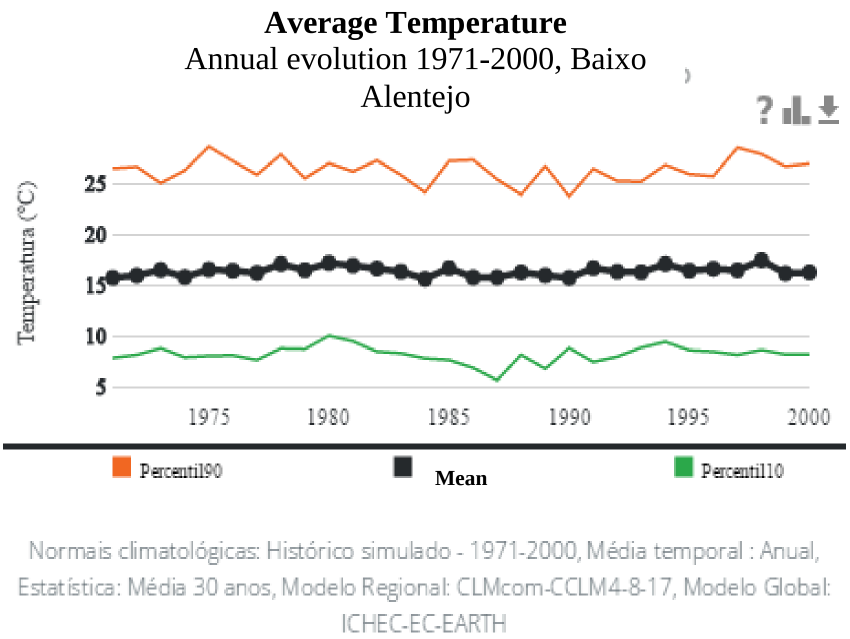


Figure 2.2 - Koppen Classification of Portugal´s climate. This classification uses precipitation, evapotranspiration and temperature to define the climate for each region (IPMA, 2016).

In the sub-region of Baixo Alentejo, the annual average temperature is 15.8ºC. The average minimum temperature can reach 10.8ºC, and the average maximum temperature can reach 21.3ºC (Figure 2.3) (Portal do Clima, 2016).





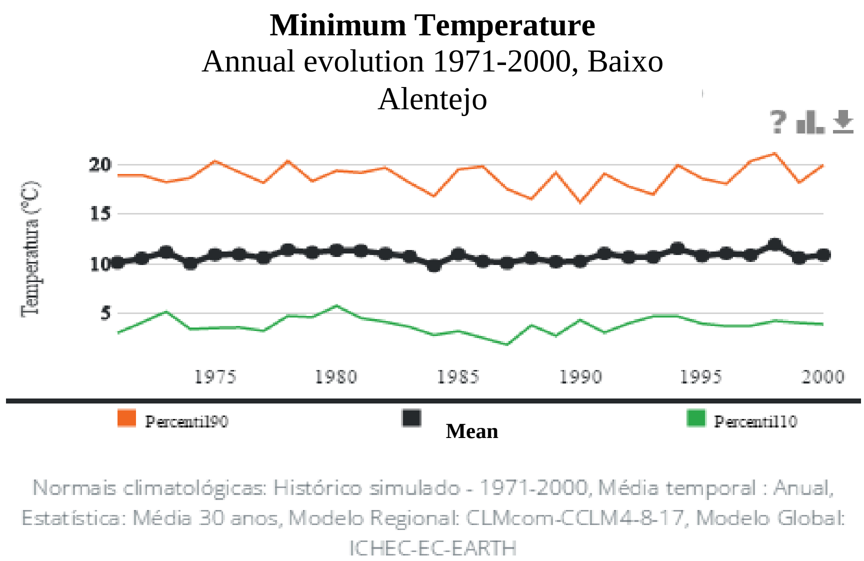
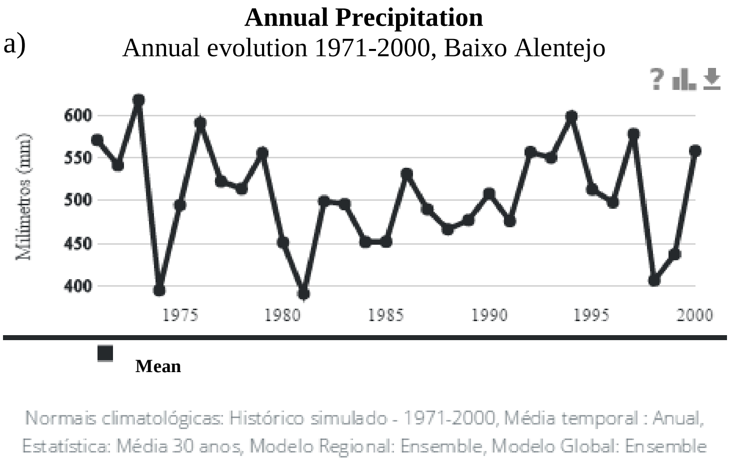


Figure 2.3 - Average, maximum, and minimum temperature in Baixo Alentejo (Portal do Clima, 2016).

Annual precipitation for the sub-region of Baixo Alentejo is 506.2 mm. Most of the precipitation occurs between October and April, reducing its value in May and in increasing in October. Between June and September, the occurrence of precipitation is absent, registering an amount lower than 20 mm. Normally, December is the rainiest month with, in average, 77.7 mm; and July is the driest, registering in average 5.5 mm (Fig 2.4) (Portal do Clima, 2016).

a)



b)

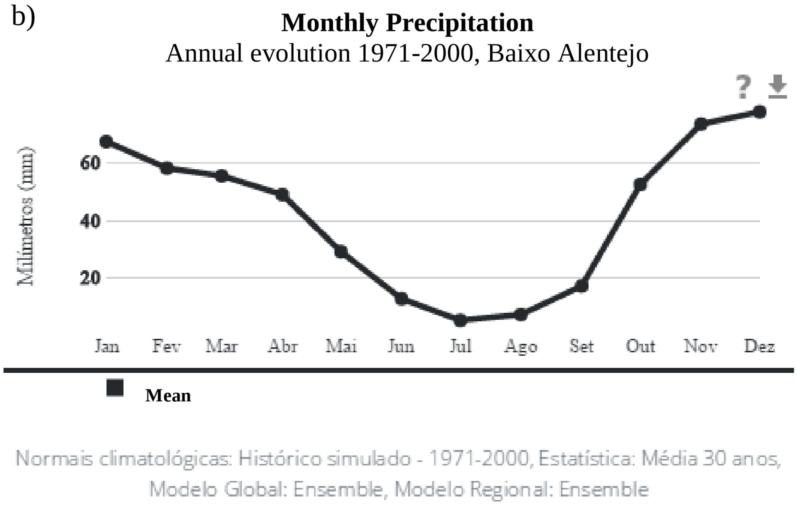


Figure 2.4 – Precipitation for Baixo Alentjo. Graphic a) represents the annual precipitation and graphic b) the monthly precipitation distribution, both for the period between 1971-2000 (Portal do Clima, 2016).

More recent data shows that in the last 15 years the annual average precipitation for Beja has been 475.7 mm, and for Mértola 273.3 mm (Table 2.1). There are clear differences in monthly precipitation amount between the two study areas, in the last 8 years (Table 2.2). Taking to account that in Baixo Alentjo the annual precipitation is 506.2 mm, we see that the amount of precipitation that occurs in Mértola is very low.

Table 2.1 - Annual precipitation from the last 15 years (2000-2015). Data provided by Project *AdaptforChange.*
*Some months were missing, so this year is probably under estimated.

Year	Amount of precipitation in Beja (mm)	Amount of precipitation in Mértola (mm)
2000	656.0	495.4
2001	620.7	459.6
2002	529.7	469.5
2003	549.6	476.2
2004	316.4	127.4
2005	335.7	100.8
2006	552.2	19.2*
2007	310.2	244.0
2008	446.7	308.2
2009	420.6	227.6
2010	788.0	280.4
2011	656.0	551.2
2012	225.2	141.5
2013	434.2	182.7
2014	560.8	239.4
2015	208.7	49.3*
Mean	475.7	273.3

Table 2.2 – Average monthly precipitation in the last 8 years (2007-2015). Data provided by Project *AdaptforChange*.

Month	Amount of precipitation in Beja (mm)	Amount of precipitation in Mértola (mm)
January	38.4	23.0
February	56.7	31.2
March	57.6	30.5
April	61.5	41.8
May	33.6	24.7
June	16.5	10.5
July	0.9	0.8
August	3.3	3.9
September	30.9	21.7
October	56.9	40.8
November	63.6	21.4
December	60.5	21.5
Mean	480.2	271.9

2.1.3. Use Capacity

The Alentejo region has poor soils with low fertility (Correia-Pinto & Mira Potes, 2013). In Mértola, the A, B and C classes exist in low number, with A and B being almost inexistent, occurring only in narrow strips of reduced dimensions in the background of some small valleys (Casimiro, 1993). The dominant classes are the D and E soils, especially the E. Nearly 80% of Mértola´s total area is inappropriate for agricultural practices, pastures, bushes, and forestry, with high rates of erosion risk. A large number percentage of the area is suitable for natural or forestry vegetation protection or verification (Casimiro, 1993; Lecoq, 2000; Esteves, 2013). The northwest region of Mértola has soils with better quality, concentrating most of the explorations. In the opposite, the east and south, the soils are extremely poor, with shallow or skeletal Lithosols. (Casimiro, 1993; Esteves, 2013). Beja has a higher percentage of class A soils (6.1%) and low percentage of E (46.4%), when compared with Mértola. The B, C and D, classes have higher in percentage in Beja (Table 2.3) (Casimiro, 1993).

Table 2.3 - Different classes of soils found in the study areas. Adapted from Casimiro, 1993.

District	Soil A (%)	Soil B (%)	Soil C (%)	Soil D (%)	Soil E (%)
Mértola	0.1	0.6	2.3	16.3	80.7
Beja	6.1	11.2	15.7	19.3	46.4

In the study areas, we identified 4 major groups of soils and three sub-groups: a) Eutric Cambisols with sedimentary rock post-Palaeolithic; b) Ferric Luvisols; c) Chromic Luvisols d) Eutric Lithosols and e) Vertisols. Due to the lack of samples from Vertisols, Ferric Luvisols, and Chromic Luvisols, we decided to ignore the samples with Vertisols and agglomerate the Ferric and the Chromic sub-groups in one group, the Luvisols. So, at the end, we got three groups of Soils. The main characteristics and differences between these soils are synthetized in Table 2.4.

Table 2.4 – Characterization of the three soils. Information compiled from Soil Atlas of Europe (Jones *et al.*, 2005), COS2007, Soils of the European Union (Tóth *et al.*, 2008), and World reference base for soil resources 2014 (IUSS Working Group WRB, 2015).

Soil	Characterization	Soil use	Area in EU (km^2)	Subgroup	Characterization	Soil use	Area in EU (km^2)	Distribution	Acidity and Alkalinity	Soils pH	Location
Cambisols	Young soils in a continuous process of pedological maturation Soil formation distinguish by soil color and/or structure formation below the surface horizon Occur in wide variety of environments Brown Soils	Very productive for agricultural use, especially in loess areas	1107598	Eutric	Possessing a base saturation (in 1M ammonium acetate at pH 7.0) of more than 50 percent, in some section between 20 and 100 cm above soil surface, or in a layer directly above a lithic contact in Leptosols	Cultivation of all kinds of crops In irrigated or non-irrigated alluvial plains are mainly used for food and oil crop production	339972	Most of Europe	Dominantly Acids	5,6 - 6,5	Beja
Lithosols or Leptosols	Shallow soil over hard rock and comprise of very gravelly or highly calcareous material Limited pedogenic development Structure poorly develop and weak expressed horizons Undulating lands and steep slopes, mainly in mountainous regions. Also, found in areas where the soil is highly eroded Very extensive soils Well drained Soils	More suitable for forestry Agriculture use Potential resource for grazing	435713	Eutric	Possessing a base saturation (in 1M ammonium acetate at pH 7.0) of more than 50 percent, in some section between 20 and 100 cm above soil surface, or in a layer directly above a lithic contact in Leptosols		34662	Exclusive to the Mediterranean and Balkan countries	Dominantly Acids	5,6 - 6,5	Mértola
Luvisols	Well develop soils, with noticeable textures differences within the profile Surface horizon depleted of clay, and subsurface with high concentration of clay (argic horizon) and base saturation Porous and well aerated. Chemical properties and nutrient content vary with parent material and pedogenetic history Occur on well drained landscapes	Fertile soil suitable for agriculture use In the Mediterranean, the upper slopes are used for extensive grazing or tree crops plantations Lower slopes, wheat and/or sugar cultivations	610941	–	–	–	–	–	Dominantly Acids	5,6 - 6,5	Mértola and Beja

2.1.4. Study areas choosing parameters

The chosen study areas exist in a semi-arid region with high to moderate susceptibility to desertification, where the soils susceptibility to desertification varies between very high to high. Once our main objective is to study the adaptive capacity of biodiverse pastures to climate change, this made the perfect place to analyses how the implementation of the biodiverse pastures would improve the vegetation density in these types of conditions. For a more correct comparison of the different type of pastures, we chose the areas with the similar climatic conditions and types of soils. The Landsat 7 Scan Line Corrector defect (going to be more explain in another sub-topic) had also some influence in area choosing, because not all the image from the area had usable information, due to information gaps.

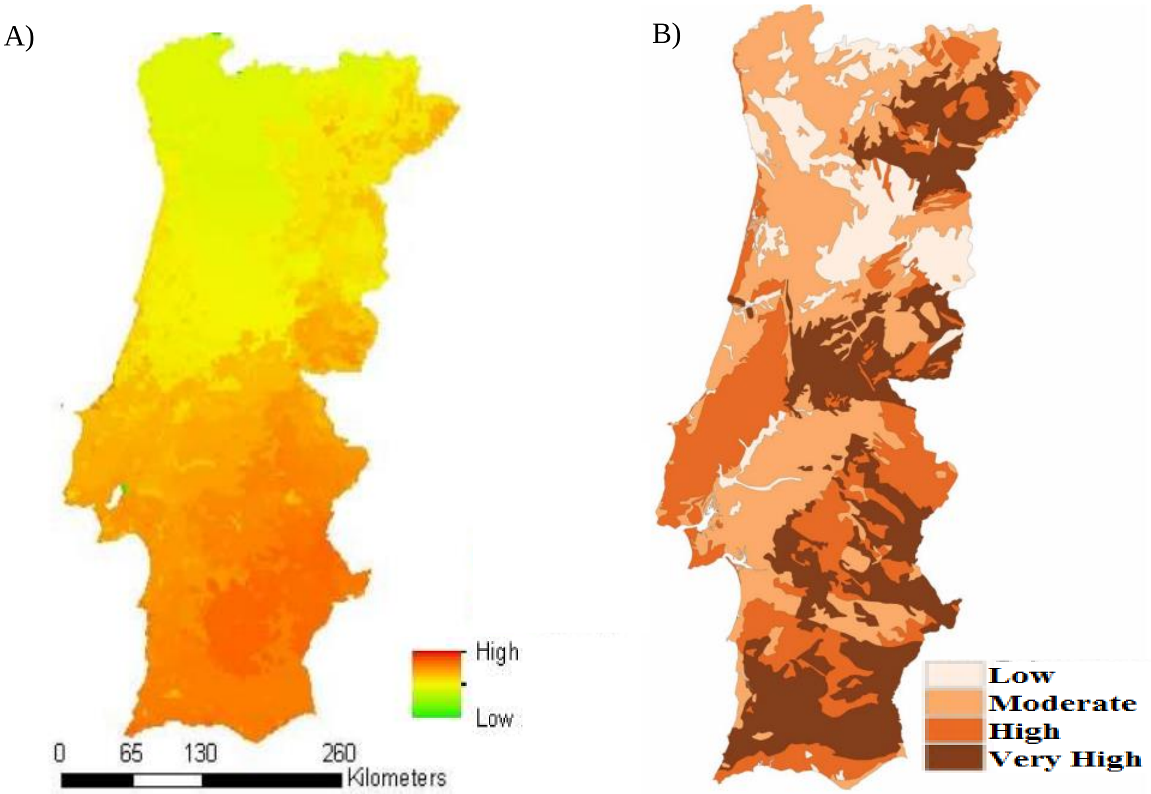


Figure 2.5 – A) Desertification susceptibility index (Adapted from: CNCCD, 2012), and B) Index of soil susceptibility to desertification (Adapted from: do Rosário, 2004).

2.2. Satellite Imagery

The satellite imagery used in this study was obtained from the Landsat Project. This project has, along the years, acquired space-based images of the Earth's land surface, providing very useful data for land use and land changes investigation (U.S. Geological Survey, 2016). The Landsat imagery were downloaded from the U.S. Department of the Interior official website - http://earthexplorer.usgs.gov/.

For this study, it was necessary three different satellites from the Landsat Project, in order to conduct analyses on the pastures productivity between 2007-2014. The chosen satellites were: Landsat 5 Thematic Mapper (TM) (L5), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) (L7) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (L8). These satellites were all launched in different decades, L5 being the oldest one, launched in 1984, and L8 the most recent one, in operation since 2013 (Table 2.5) (U.S. Geological Survey, 2016).

Table 2.5 – Landsat characteristics. Adapted from: U.S. Geological Survey (2012).

Landsat	Launched year	Decommissioned	Sensors	Orbit
L5	1984	2013	MSS, TM	16 days/ 705km
L6	1993	Failed to launch	ETM	16 days/ 705km
L7	1999	Operational	ETM+	16 days/ 705km
L8	2013	Operational	OLI, TIRS	16 days/ 705km

The three Landsat satellites orbit the Earth at an altitude of 705 kilometers (438 miles), in a 185-kilometer (115-mile) line, moving in a north to south sense over the sunlit side of the planet, and in a sun synchronous orbit (U.S. Geological Survey, 2016).

To facilitate the reading, the Table 2.6 summarizes the different bands characteristics for each Landsat satellite used in the study.

Table 2.6 - Bands characteristics for each Landsat. Adapted from: U.S. Geological Survey (2016).

	Landsat 8 OLI/TIRS			Landsat 7 ETM+			Landsat 5 TM		
Band Designation	**Bands**	**Wavelength**	**Resolution**	**Bands**	**Wavelength**	**Resolution**	**Bands**	**Wavelength**	**Resolution**
Coastal/Aerosol	Band 1	0.43–0.45	30	--	--	--	--	--	--
Blue	Band 2	0.45–0.51	30	Band 1	0.45–0.52	30	Band 1	0.45–0.52	30
Green	Band 3	0.53–0.59	30	Band 2	0.52–0.60	30	Band 2	0.52–0.60	30
Red	Band 4	0.64–0.67	30	Band 3	0.63–0.69	30	Band 3	0.63–0.69	30
Near-Infrared	Band 5	0.85–0.88	30	Band 4	0.77–0.90	30	Band 4	0.77–0.90	30
Shortwave infrared- 1	Band 6	1.57–1.65	30	Band 5	1.55–1.75	30	Band 5	1.55–1.75	30
Shortwave infrared- 2	Band 7	2.11–2.29	30	Band 7	2.09–2.35	30	Band 7	2.09–2.35	30
Panchromatic	Band 8	0.50–0.68	15	Band 8	0.52–0.90	15	--	--	--
Cirrus	Band 9	1.36–1.38	30	--	--	--	--	--	--
Thermal	Band 10 T1	10.60–11.19	100	Band 6	10.40–12.50	120	Band 6	10.40–12.50	120
Thermal	Band 11 T1	11.50–12.51	100	--	--	--	--	--	--

When choosing the images, it was given preference to days where the atmospheric moisture content and aerosols were low, because NDVI is also affected by atmospheric conditions, affecting the radiance reflection (Ding, 2012). When working with Landsat 7, the study areas had to be located in the center of the image or as far as possible from the data gaps that existed in the images.

In 2003, due to a malfunction in the Scan Line Corrector (SLC), unusual gaps began to appear within the data collected by the ETM+ instrument. The SLC compensates the forward motion of the satellite and aligns the forward and reverse scans, so that the creation of an image can be possible. The malfunction led to a 22 % of image data loss, resulting in data gaps forming in alternating wedges that increase in width from the center to the edge of the image. Attempted repairs of the SLC have been unsuccessful. Some methods have been established so that users can fill the data gaps (U.S. Geological Survey, 2016).

2.2.1. Image Calibration and Processing

We chose QGIS 2.10.1 Pisa software for image processing. The QGIS software is a free and open source geographic information system (GIS), that gives his users the capability of working with many vectors, rasters and databases, and, also, a lot formats and functionalities. (QGIS, 2016).

Before using the satellite images, it was necessary to convert the data from Digital Numbers (DN) to Reflectance. The radiometers have different types of calibrations, so that the values taken would be as consistent as possible and closer to reality.

2.2.2. Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+)

The calibration process for Landsat 5 and Landsat 7 requires the conversion of digital numbers (DN) into reflectance data. Digital numbers are values in 8-bit format (0-255), not yet calibrated into a physically meaningful unit. For to be possible to create vegetation indexes it is necessary to convert these numbers into reflectance, which is a physical measure (Firl & Carter, 2011).

The DN conversion to reflectance process for L5 and L7 goes as such (Firl & Carter, 2011):

1) Convert L5 DN of the specific bands into DN equivalent to L7 (DN7), so that it is possible to apply to L7 DN conversion method. For this, we apply the equation 1,

Equation 1: $\mathbf{DN7 = (\, slope_{\lambda} * DN5) + intercept;}$

where DN7 is the Landsat 7 ETM+ equivalent DN data; DN5 is the Landsat 5 TM DN data; the slope and intercept are band-specific numbers given by the inverse of those found in Vogelmann *et al.* (2001). The slope and intercept values are given in Table 2.7

2) Convert DN7 in radiance data from specific bands (explained in NDVI section), by applying equation 2:

Equation 2: $\mathbf{L_{\lambda} = (gain_{\lambda} \times DN7) + bias_{\lambda},}$

where $\mathbf{L_{\lambda}}$ is the calculated radiance; DN7, the Landsat 7 ETM+ DN data; and the **gain** and **bias** are band-specific values (Table 2.7).

3) Convert radiance data from the bands into reflectance data, applying equation 3:

Equation 3: $\mathbf{R_{\lambda} = \pi \times L_{\lambda} \times d^2 / E_{sun,\lambda} \times \sin(\theta_{SE}),}$

where $\mathbf{R_{\lambda}}$ is the reflectance; $\mathbf{L_{\lambda}}$ is the radiance data calculated previously, **d** is the earth-sun distance (in astronomical units), $\mathbf{E_{sun,\lambda}}$ is the band-specific solar exo-atmospheric irradiance emitted by the sun (Table 2.7), and $\mathbf{\theta_{SE}}$ is the solar elevation angle.

Table 2.7 - L5 and L7 equation constants (Firl & Carter, 2011).

	Landsat 5		Landsat 7		
Band	**Slope**	**Intercept**	**Gain**	**Bias**	**$E_{sun,\lambda}$ ($W.m^{-2}.\mu m^{-1}$)**
1	0.943	4.21	0.77874	-6,98	1997
2	1.776	2.58	0.79882	-7,2	1812
3	1.538	2.50	0,62165	-5,62	1533
4	1.427	4.80	0.63976	-5,74	1039
5	0.984	6.96	0.12622	-1,13	230,8
7	1.304	5.76	0.04390	-0,39	84,9

After this last data conversion, the data was ready to be used in the creation of the NDVI images.

2.2.3. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

For the Landsat 8, the DN conversion to reflectance data was also necessary, but the process was different from the previous Landsat´s (GrindGIS, 2015):

1) To convert DN values of specific bands into reflectance data, using equation 1:

Equation 1: $\boldsymbol{\rho\lambda' = M\rho \,.\, Qcal + A\rho}$,

where **ρλ'** is the TOA planetary reflectance, without correction for solar angle; **Mρ**, the band-specific multiplicative rescaling factor from the metadata; **Aρ**, the band-specific additive rescaling factor from the metadata; and **Qcal** is the quantized and calibrated standard product pixel values (DN).

2) Perform a correction of the reflectance values with sun angle, using equation 2:

Equation 2: $\boldsymbol{\rho_\lambda = \rho_\lambda\,' / \sin\theta_{SE}}$,

where $\boldsymbol{\rho_\lambda}$ is the TOA planetary reflectance and $\boldsymbol{\theta_{SE}}$ is the sun elevation angle.

2.2.4 Normalized Differentiation Vegetation Index

After all the images were correctly calibrated, we proceeded to calculate de Normalized Differentiation Vegetation Index (NDVI).

The NDVI is an instrument use to study the photosynthesis activity and biomass production in a vegetation (Sobrino *et al.*, 2008). Commonly used in studies regarding vegetable communities, the NDVI is also a good index to use in production analyses in pastures (Flynn, 2006).

The application of the NDVI leads to the creation of a single-band dataset that shows the greenness of the image. The index ratio varies between -1 and 1, where: values close to zero represent rock and bare soil; negative values represent water, snow and clouds; and the increase in the positive NDVI value means greener vegetation (GrindGIS, 2015).

The equation to obtain this index is:

Equation 1: $\mathbf{NDVI} = \frac{(\mathbf{NIR} - \mathbf{RED})}{(\mathbf{NIR} + \mathbf{RED})}$

where **NIR** is the near infrared band and **RED** is the red band. The bands variate through the Landsat satellites, in Landsat 8, the bands 5 and 4 are the NIR and RED bands, respectively, but for Landsat 7 and 5, these bands are the Bands 4 and 3 (table 4).

The NDVI is influenced by soil characteristics (type, texture, moisture, organic matter, color, fertility, and the presence of iron oxides), geomorphology, vegetation (dead plant material, leaf angle) (Wang *et al.* 2003; Flynn, 2006), precipitation and temperature (Wang *et al.* 2003). In this study, we are only going to focus on two characteristics: soil, and precipitation.

The focus, when applying the NDVI, was to study the density variation across each season and years, so that we could analyze the main differences between the pastures in growth limited conditions. In order to conduct the study, we tried to use images from 12 months of the year.

Not all images were useable, meaning that in some of the years the seasons were underrepresented or just absent. To compensate the unusable images from one Landsat, we used the images from previous Landsat. Still, some years had poorly represented seasons, like 2012 and 2008, because there were not Landsat 5 images available to compensate lack of usable Landsat 7 images.

2.3. Sampling design

In association with *Terraprima*, we chose a total of 65 Biodiverse Pastures from their data base. 33 pastures were from Mértola and 32 from Beja. Then, we chose 82 nearby natural pastures for the control comparison.

The biodiverse pastures had to be in rainfed conditions, so that the pastures would be in the normal water limitation conditions. Pastures in irrigation conditions are not limited by droughts and water scarcity events, which means that water availability is not limiting their growth and productivity, which is the main why they were not use for our study.

To correlate the influence of soil texture, pH, and color with the productivity of the SBPPRL, we used the "*Atlas Digital do Ambiente*" for Portugal. This Atlas can be used in GIS, allowing the users a simpler way to access a more environmental geographic information (APA, 2016). Due to a confidentiality agreement with *Terraprima*, to respect the farmer's privacy, the biodiverse pasture limits could not be showed in this thesis.

The polygons for the Natural Pastures were created in QGIS, version 2.10.1 'Pisa' for Windows, using the shapefile "*Carta de Ocupação do Solo 2007*" (COS 2007) to choose the *Montado* areas. There is a more recent COS, but the 2007 COS was the only one available for free use. These areas were identified in the shapefile as Agro-silvo-pastoral (SAF) with pastures (Figure 2.5). These SAF can appear associated with Holm oak, Cork oak or a mixture of the two. The natural pastures chosen had to be in the same area of the or in nearby the biodiverse pastures, so to be sure they were in the same climatic and soil conditions has the biodiverse pastures. The pastures had to be similar in area, so that no over or under evaluation occurred in this study. Polygons were created in the chosen areas, so that only pastures with highly dispersed trees were considered.

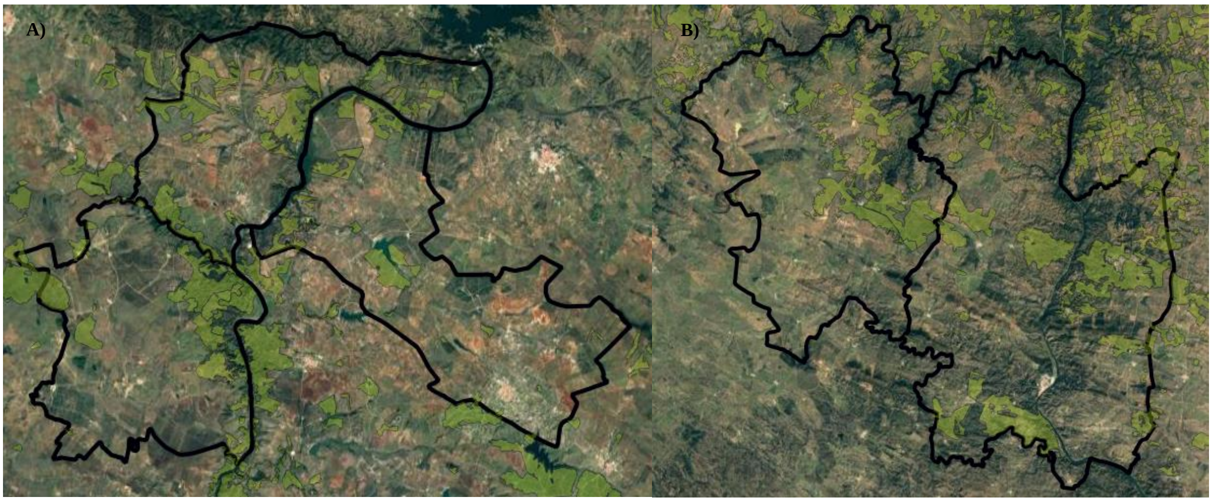


Figure 2.6 - Agro-sylvio-pastoral (SAF) with pastures distribution (light green) in A) Beja and B) Mértola.

The area for both types of pastures were less than one hectare. The biggest biodiverse pastures area in Mértola had 0.9981 ha as for Beja the area was smaller, 0.9973 ha. The smallest area observed for the same pastures in Mértola was 0.1296 ha, and for Beja was 0.2860 ha. As for Natural pastures, the biggest area in obtained in Mértola was 0.9605 ha, and the smaller was 0.5379 ha. In Beja, the biggest area was 0.9813 ha, the smallest was 0.1625 ha. In the ratio analyses, only pastures with similar areas were used.

Besides comparing biodiverse pastures with natural pastures, we also wanted to know if the implementation of the biodiverse pastures had considerable changes in the vegetation density in the respective farms. So, we created a third pasture category, the Previous Pastures, and compared them with the same nearby natural pastures of the biodiverse, and with the biodiverse pastures. The previous pastures are pastures or cultures existed in the exact same area as the biodiverse pastures did during the contract years. Changes in NDVI patterns in that area would allow us, to understand if the implementation of the biodiverse pastures had any positive or negative affect in productivity of that area. The absence of records that refer to what kind of pastures or cultures that existed before the implementation of the biodiverse pastures in *Terraprima*, led us to not specify the type of pasture or culture, and only consider them as previous pastures.

For a better understanding of the applied classification, the Figure 2.7 resumes the pastures classification used in this study.

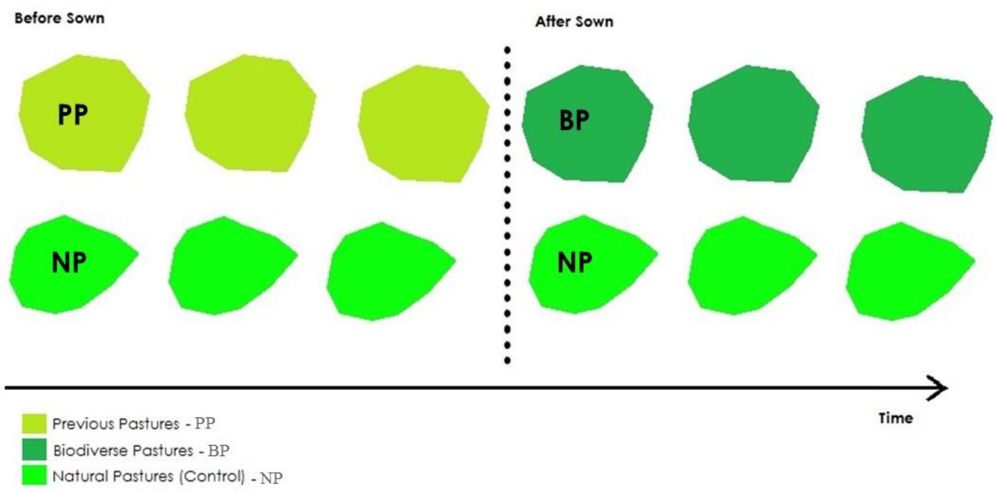


Figure 2.7 - Pastures classification. After Sown, the dark green pastures are biodiverse pastures, before pastures the light green are the pastures that existed before the implementation of the biodiverse pastures. The Natural pastures, represented by the bellow green polygons, are the nearby pastures used for the control comparison.

Before obtaining the NDVI for every polygon, we needed to take in to account the tree density and the presence of bushes. In this study, the different vegetation NDVI´s were not discriminated. The reflectance from the trees canopy and the understory can vary seasonally and their temporal cycles are different (Pisek *et al.*, 2015), meaning that in some seasons the values obtained can be influenced be the presence different vegetation. To conduct the NDVI vegetation division, it would have been necessary field dislocations, to take reflectance samples from the understory, so it would be possible to correctly associate the NDVI with the correct vegetation. The procedure would be very difficult to accomplish with the time limitations of this kind of dissertation. Even with the satellite imagery to separate the different covers, it would be necessary high resolution imagery. So, to reduce the tree, buildings and water puddles noise, we conducted a 30meter reduction, from the polygon limits to the center. The procedure was conducted in QGIS, using the *Buffer Tool*, applying a 30meter negative buffer. When creating the natural pastures polygons, we also took this into account and chose the areas with the lowest tree density possible and, also. applied the 30-meter reduction. The applied reduction was considered sufficient to decrease, considerably, the other vegetation influence on the NDVI, because being The Montado characterized by high tree dispersion and usual shrub control performed, the probability of getting interference from other vegetation is low.

Using the option *Local Statistics* from QGIS tools, we extracted the NDVI values from the polygons to a summarized table. Only average values were use, because the lack of image replications for each month would not allow the usage, with total confidence, of max or minimum NDVI values, due to the high possibility of these values being outliers.

2.4. Precipitation

Precipitation is one of the main factors that affect vegetation growth in semi-arid regions, and that is why we decided to compare the biodiverse and natural pastures responses to different precipitations patterns verified between 2007 and 2014.

To study the influence of precipitation on the pastures, we consider as study variables, the annual precipitation (Bio 12) and precipitation anomaly.

Annual precipitation allows us to understand annual precipitation intake and the differences in the amount of precipitation between the years. This variable is obtained by summing the monthly precipitation in a year (Equation 1) (O'Donnell *et al.*, 2012).

Equation 1: **Bio 12 =** $\boldsymbol{\sum_{i=1}^{i=12} PPT}$

Precipitation anomaly is important to comprehend which years had scarcity of water intake or over precipitation, using the average precipitation that occurred in the last 15 years (2000-2015) as reference. To calculate this variable, we need annual precipitation about and subtract it of average precipitation in the last 15 years (Equation 2).

Equation 2: Precipitation anomaly = **Bio 12 -** $\boldsymbol{\frac{\sum_{i=1}^{i=15} PPT}{15}}$

The precipitation data were obtained IPMA climatic stations, namely, Mértola/Vale Formoso (CODE: 1210863) and Beja (CODE: 1200562) Stations. The acquired data were ceded by *AdaptForChange* Project

2.5. Statistic work

The statistic work focused on Kruskal-Wallis ANOVA tests and Spearman correlation. Seeing that our data did not fulfil the parametric assumptions (normality or homogeneity), we had to apply the non-parametric tests in order to verify the significance of our tests. For the Kruskal-Wallis test, we wanted to verify if there were no differences between the three pastures (Ho), or if, in fact, there was (H1), with the significance value of 0.05. This statistic test was performed in the *RStudio* software. The graphic bars were created on *Excel* and the boxplots in *RStudio*.

Chapter 3 - Results

3.1 Seasonally NDVI comparison

We divided each year in 3 seasons – winter, spring, and autumn – in the different study areas. The dividing in seasons would allow us to compare the NDVI differences between the three pastures. The month division for each season goes as follows:

1. Winter – December, January, and February
2. Spring – March, April, and May
3. Autumn – September, October, and November

The three seasons were chosen because in the Mediterranean the growing season starts after the first precipitation of Autumn, occurring a rapid growth; and, as the winter arrives, the grasslands maintain active until early spring. Summer was ignored, because the senescence process starts in May (Jongen *et al.*, 2011) and, when the hot season arrives, the pastures are dry up and their photosynthetic rate is very low. Some of the seasons are under estimated, especially the Spring and Winter, due to the absence of some months. These seasons are, in some years, only represented by one month (May, April, or March) or absent if there were not representable months.

From Figure 3.1, we can see that the natural pastures were very similar in NDVI to biodiverse pastures and previous pastures in the Spring and Winter. In Autumn, the differences were more apparent, with previous pastures having the higher NDVI and the biodiverse and natural pastures having very similar values. As we can see by the Kruskal-Wallis test, there were no significant differences, once the obtained p-values were all higher that significant value, 0.05.

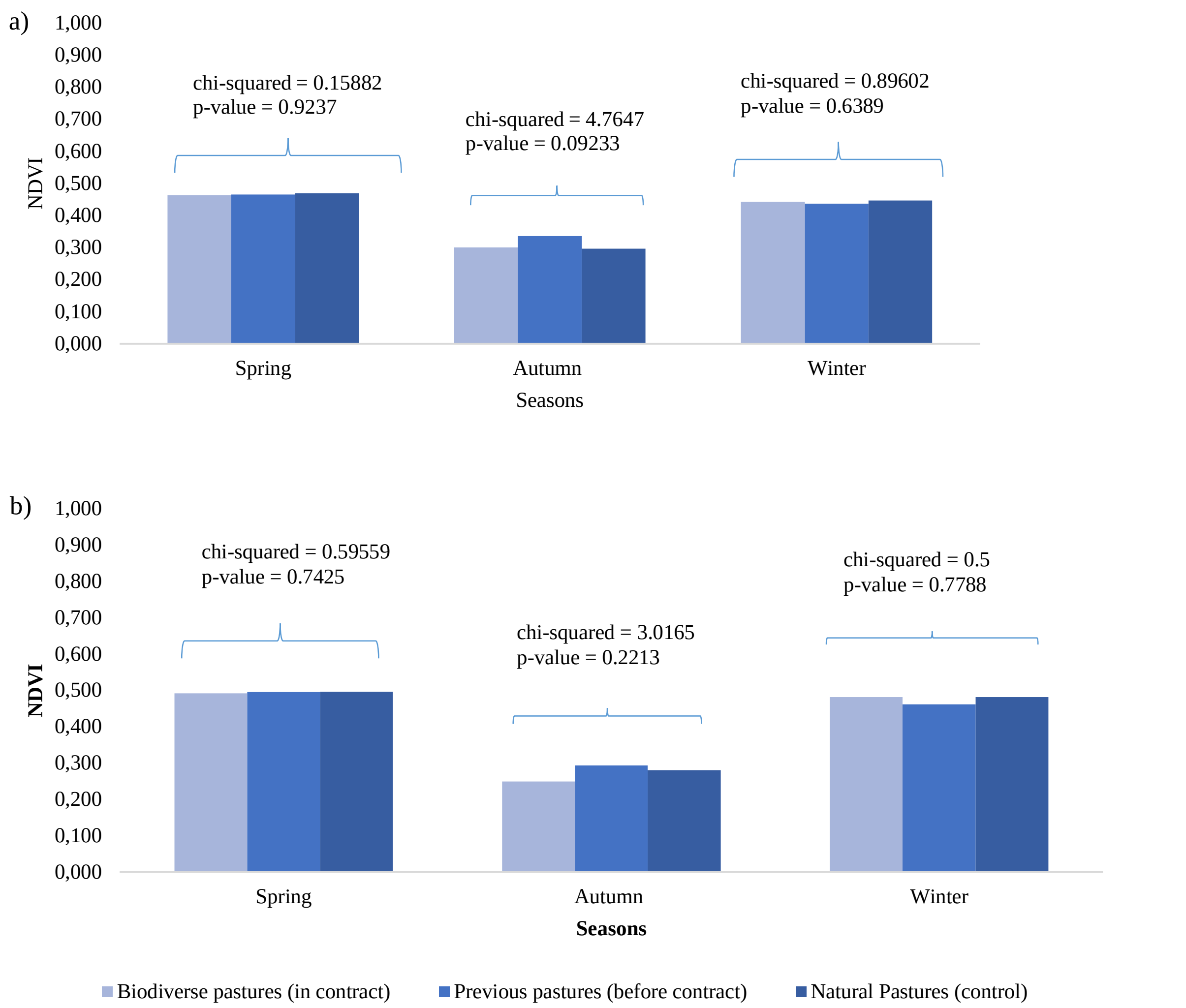


Figure 3.1 - Seasonal NDVI for a) Beja, and b) Mértola. The p-values above the bars represent the Kruskal-Wallis test results, and show that the differences between the pastures were significant.

3.2 Implementation changes to the NDVI

In this and the following tests we created NDVI ratios. These ratios by the following equations:

1. Ratio Biodiverse/Natural = $\frac{\text{average annual NDVI of biodiverse}}{\text{average annual NDVI of natural pastures}}$
2. Ratio Previous/Natural = $\frac{\text{average annual NDVI of previous}}{\text{average annual NDVI of natural pastures}}$

The ratios helped us camouflage the NDVI fluctuations in each year, allowing a better analysis of the NDVI overall. The chosen pastures had to be in the surroundings and be similar in area, so that the influence of each pasture in the ratio would be similar. We obtained 48 ratios, which represent different study areas and soils (Table 3.1).

Table 3.1- Ratio division according with study areas and soils.

Ratio division in study areas		Ratio division in Soils		
Mértola	Beja	Cambisols	Lithosols	Luvisols
27	21	18	20	10

The Figure 3.2 represents the changes in NDVI ratios of biodiverse/natural. In this analyse, we used the biodiverse ratios from the years of implementation and the average of previous/natural ratio, as the control ratios, seeing that they represent what was the NDVI values before the implementation.

According with the evolution graphic, from 48 pastures analyzed, 28 had high NDVI ratios, and 20 low or similar NDVI ratios, when compared with the ratios that existed before the implementation. One interesting to notice was that between study areas, approximately the same number of pastures had higher values of ratios, once compared to the ratios before the implementation (15 pastures from Mértola and 13 from Beja).

Furthermore, the figure highlights the differences between the years of implementation. Most of the dots concentrate near the line that represents what would be expected without the implementation of the biodiverse pastures. This means that the NDVI values, obtained after the implementation, do not vary much from what it would be expected. A large portion of dots from the two first years locate themselves above the diagonal line, meaning that they had NDVI ratios higher than expected; as for the third year, most of its dots are concentrated under the diagonal line, meaning that most of the ratios at this year had ratios above the expected.

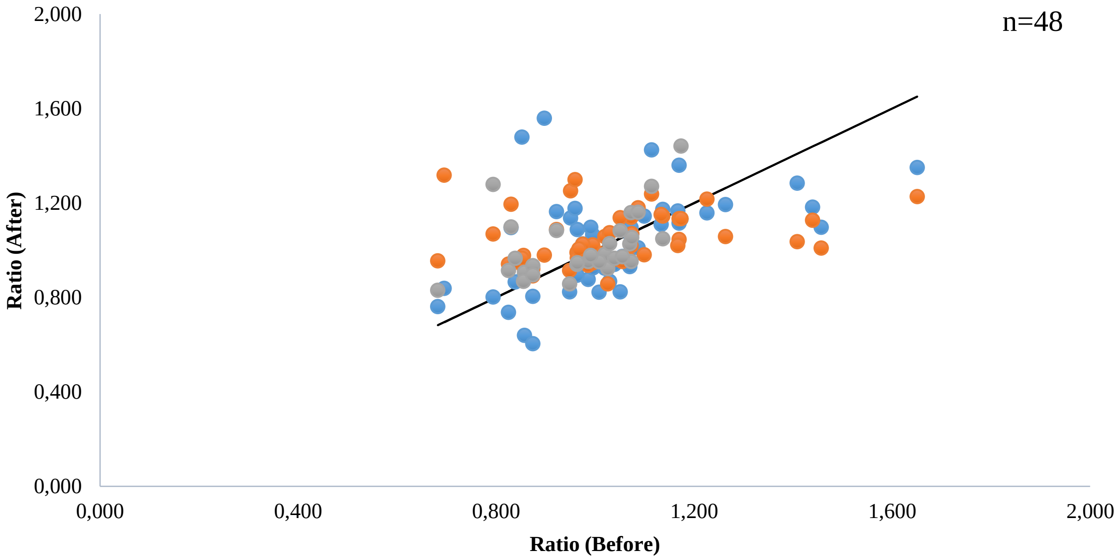


Figure 3.2 - Biodiverse Pastures evolution. The x-axis represents the average of the previous ratios and the y-axis is the ratios after the implementation of the biodiverse pastures. Each dot represents the biodiverse pastures in different years. The blue dots represent first-year, the orange dots the second-year, and grey dots the third-year. The diagonal line represents the expected evolution of the local system without the biodiverse pastures. If the points, biodiverse pastures, are above the line, it means that the system had productivity improvement; under the line means that the system had a loss in productivity.

3.3 Pastures ratios comparison

In this analyze, we decided to ignore differences in study areas, climate, and soils, and compared the average between previous/natural ratios and biodiverse/natural ratios.

The difference between ratios average was very small, with biodiverse ratios registering 1.032 and previous ratios only 1.031. Furthermore, the ratios were very close to 1, which means that the NDVI from these pastures were similar to the NDVI from the natural pastures. Despite the small differences between the natural and the biodiverse, and previous pastures with the natural pastures in the study areas, they were not statistical significant (Figure 3.3).

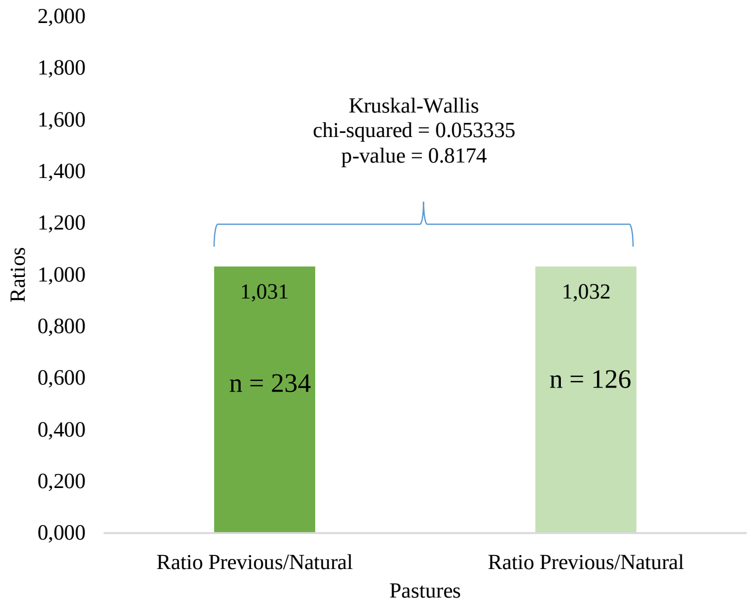


Figure 3.3 – Ratio Previous/Natural comparison with Ratio Biodiverse/Natural.

The boxplot from Figure 3.4 shows the ratios distribution for each pasture. We can see that the medians between the two type of pastures are very similar, which could be explained by the large number of outliers observed in the previous pastures, that pull the median for the previous ratios upward. Most of the biodiverse ratios concentrate near the third quartile, with three outliers pulling the median upward, and one downward. As for the previous ratios, they are more concentrated near the first quartile and a considerable number of ratios are concentrated near the third quartile.

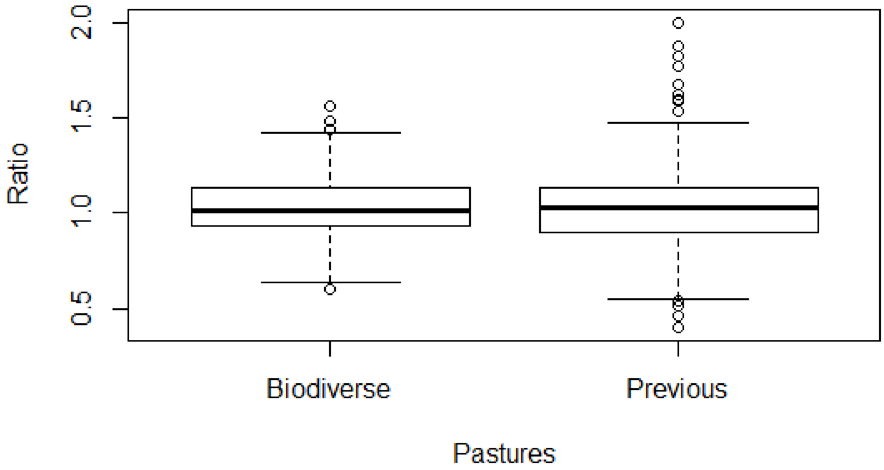


Figure 3.4 – The Boxplot explaining ratio variation between previous and biodiverse pastures.

3.4. Local ratio comparison

The ratios were different in the two study areas (Figure 3.5). In Beja, the biodiverse/natural ratios were lower than previous/natural, and in Mértola, the opposite was observed, the biodiverse ratios were higher, when compared with the previous ratios. The ratios show us, in fact, that there is some difference in NDVI values between biodiverse pastures and the local natural pastures, but this difference was very small, due to the biodiverse/natural ratios were modestly higher than 1 (1.016). The Kruskal-Wallis ANOVA test found no significant differences between the pastures ratios in Beja (p=0.089), and significant differences between pastures in Mértola (p=0.040).

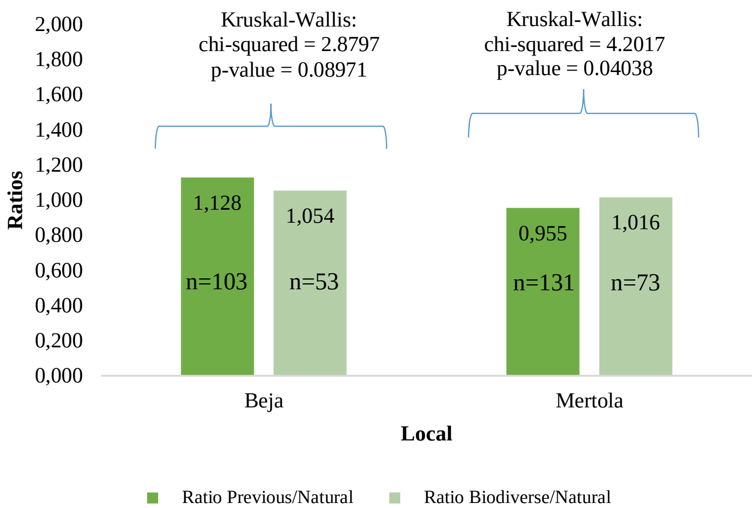


Figure 3.5 - Ratio comparison between the two study areas.

3.5. Ratio variation in different types of soil

In this analysis, we compared the biodiverse/natural ratios with previous/natural ratios in different types of soils. To perform this analyses, we separated the two ratios in the three types of soil, and then, for each soil, we calculated the average of the NDVI for the biodiverse ratios and then for the previous ratios. The data demonstrated similar ratios between biodiverse and previous in Lithosols, different ratios in Cambisols, and slight differences in the Luvisols (Figure 3.6). The previous pastures had high ratios (1.140) and low biodiverse pastures (1.045) in Cambisols. In the Luvisols, the opposite occurred, the biodiverse had higher ratios (1.125) and low previous pastures ratios (0.964). The differences in Lithosols were very small (previous=0.963 and biodiverse=0.980). The Cambisols and Luvisols ratios were modestly higher than 1, which means that the NDVI of previous pastures and biodiverse pastures were not very different from the natural pastures NDVI. As for the Lithosols, the ratios were lower than 1, meaning that the NDVI from these pastures as lower than the natural pastures.

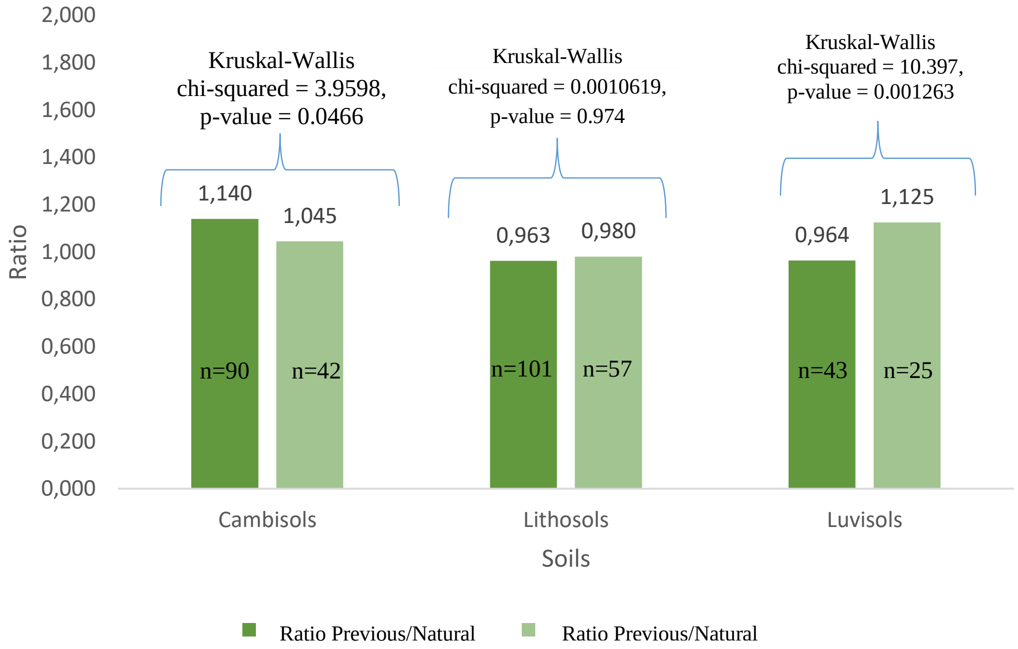


Figure 3.6 - Ratio variation in different types of soils.

The Figure 3.7 displays the ratio variation biodiverse/natural ratios across the three years of implementation of the biodiverse pastures. The graphic was created by subtracting the biodiverse ratios, for each implementation year, from the average of previous ratios:

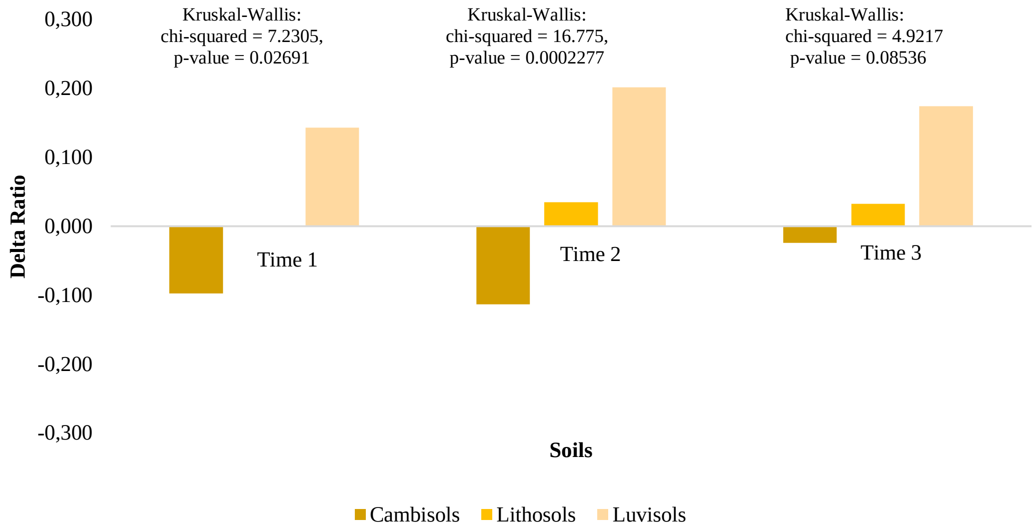
$$\mathbf{dNDVI_{time1} = ((Previous/Natural_{2007} + \ldots + Previous/Natural_{200X})/(2007 + \ldots + 200X)) - Biodiverse/Natural_{time1}}$$

where, $\mathbf{dNDVI_{time1}}$ represents the lost or gain of ratios for the first year of implementation; $\mathbf{Previous/Natural_{2007}}$ is the ratios from the first year of the study, 2007; 200X represents the year prior to the implementation of the biodiverse pastures; $\mathbf{Previous/Natural_{200X}}$ is the year prior to the implementation of the biodiverse pastures; and $\mathbf{Biodiverse/Natural_{time1}}$ is the first year of contract.

The same equation was applied for the rest of contract years (Time 2 and Time 3).

The previous ratios represent the NDVI that existed before the implementation of the biodiverse pastures and we wanted to see if there was any improvement in NDVI after the implementation. We can observe that the Lithosols and Luvisols had higher ratios in the first and second year of implementation, and a small decrease in the third year. The Cambisols very small ratios, in the three years of implementation. This shows that in this type of soil, the NDVI decreased once the previous pastures were substituted with the biodiverse pastures. The Kruskal-Wallis tests shows that the differences are significant in the first two years, and non significant in the third year.

The second graphic highlights the invidual ratio variation of the soils across the three years of implementation. It is very clear that the Cambisols had increasingly small ratios in the first two years, only improving, very rapidly, in the third year. Also, it is very clear with this graphic the increasingly high ratios in the Lithosols and the Luvisols across the years.



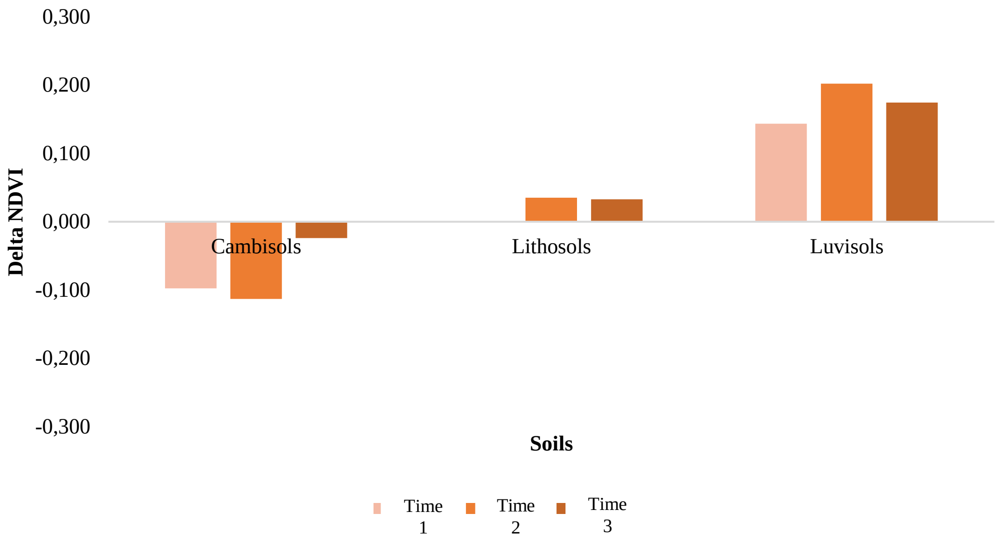


Figure 3.7 – Biodiverse/natural ratios in three different soils during the 3- years of the biodiverse pastures implementation. The average of previous/natural ratios were use as reference values in the creation of the delta ratios. In the first two years, the number of samples for each soil was higher (nº Cambisols=18, nº Luvisols=10, nº Lithosols = 20) than in the third year (nº

Cambisols=5, nº Luvisols=2, nº Lithosols = 17). This is related to the fact the number of pastures with three contracts was smaller than the two years.

The Figure 3.8 boxplots highlight the differences in ratios between the soils in the three years of implementation. During the three-year implementation, the Luvisols and the Lithosols have shown an increase of positive delta ratios (ratios that improved in NDVI) and a rising in medians. One interesting pattern we can see is, some ratios from the Luvisols and Lithosols shifted from the quartile one to the quartile three, across the years. This fact shows some NDVI increases in some ratios. The very opposite is shown in the Cambisols, ratios tend to shift to quartile one, meaning the delta ratios are more negative

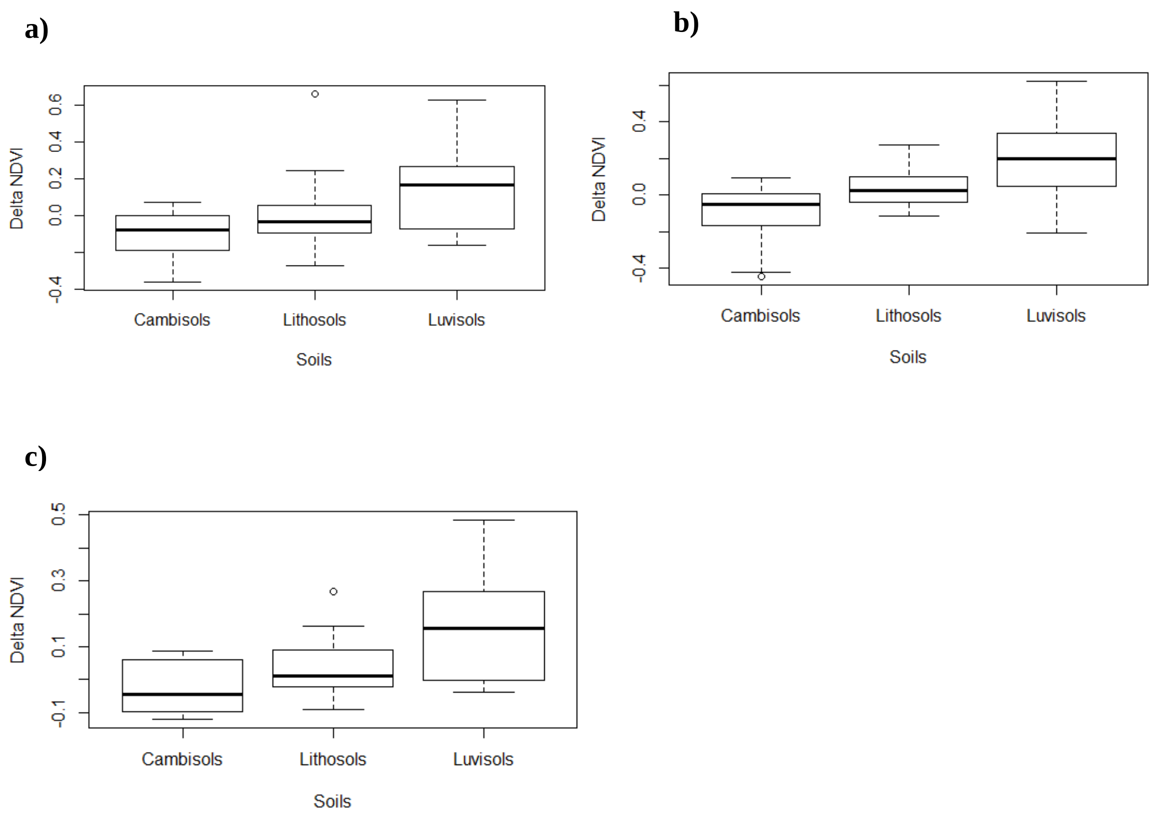


Figure 3.8 - The boxplots show the delta ratio variation in each soil for the different implementation years of the biodiverse pastures, with a) being year one, b) year two and c) year three. The pastures had different implementation years, so for this analysis we considered year one as the first-year implementation or year of contract and year three the last year of implementation or contract. Some of the pastures had only two years of implementation, so for some year two was the last year.

3.6. Influence of precipitation on ratio variation

3.6.1. Precipitation and Precipitation Anomaly

Precipitation anomalies were created to identify the years where precipitation was above and under the average. The precipitation anomaly was obtained by subtracting the current year precipitation amount from the average precipitation amount of the last 15 years (2000-2015) (Figure 3.9).

The wettest years identified were 2010 and 2011 each had, respectively, 312.3 and 180.3 mm above the average precipitation. In opposite side, the driest years were 2007 and 2012 had the lowest precipitation values, with 2012 being the most noticeable one, with less 250.5 mm than the average precipitation. In

Mértola, 2011 was the year, where the precipitation values were above normal, with 277.9 mm more than the average. The driest years was 2012, with 131.8 less than the average.

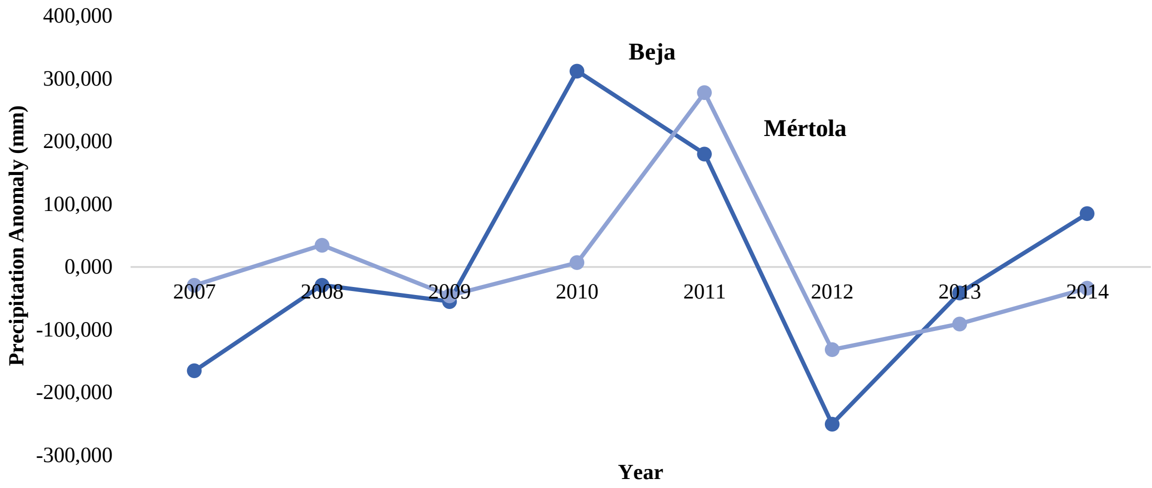


Figure 3.9 - Precipitation anomaly from the study areas.

The information from the precipitation anomalies allowed us to compare the ratios in two different categories: dry year, and wet year. The dry years were considered as being the years with the precipitation anomalies lower than 1000 mm were consider the dry years and the years with anomalies higher than 1000, were categorized as wet years. The 2007 and 2012 were identified as the dry years, and 2010, and 2011 were identified as the wet years. The ratio average for these two categories showed that in the dry years, the previous pastures had higher ratios, with 1.132, and the opposite was observed in the wet years, with the biodiverse ratios having the higher ratios, 1.237. The statistical test, The Kruskal-Wallis ANOVA, demonstrated that the differences observed were significant ($p>0.05$) (Figure 3.10).

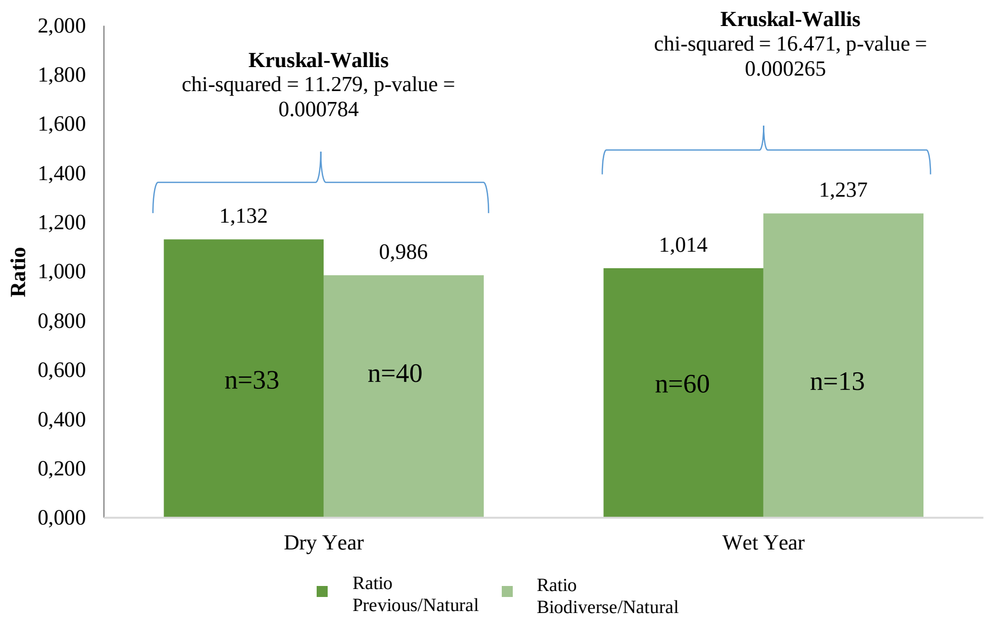


Figure 3.10 - Pasture comparison in dry and wet years.

Chapter 4 - Discussion

Many studies conducted (e.g. Crespo, 2008; Teixeira *et al.*, 2008a; Teixeira *et al.*, 2015) stated that, when compared with other type of pastures, the sown biodiverse permanent pastures rich in legumes had higher productivity rates when compared with normal grasslands. The Normalized Difference Vegetation Index applied in this analyses, demonstrated the inexistence of great differences pastures in productivity, in the form of vegetation density, between the biodiverse pastures and the natural pastures.

4.1. Season variations

When seasonal differences between natural pastures, previous pastures and biodiverse pastures were analyzed, it becomes obvious that the pastures had very similar NDVI in the seasons where the water from precipitation is more available (Winter and Spring). The data showed some differences in Autumn, with the previous pastures having the higher vegetation density. But the statistic work showed this differences were not significant. An interesting finding was the similar densities in spring, in both areas, where we expected a higher density and productivity in the biodiverse pastures, because of the higher index of area leaf and different leaf angles capable of light interception, that allow a more efficient photosynthetic process (Crespo, 2015; Teixeira *et al.*, 2015). According with Crespo (2015), grass production is higher in biodiverse pastures, so it would be expected a denser area and, consequently, higher NDVI values.

The high richness of the pastures on N, should mark a great difference, when compared with the other pastures. N-limited conditions seem to impact negatively the ecosystem´s photosynthetic capacity and biomass accumulation capacity (Sardans *et al.*, 2008). So, there should have been registered higher density differences between for sown biodiverse permanent pastures rich in legumes and the natural pastures in the growing season.

The under representation of seasons may reflect some of the results due to the probability of the sample image chosen not being representative of the optimum NDVI values. The images, like explained in the methodology, were chosen because of their low density of clouds, but this brings an important issue. By ignoring the images were the precipitation is, in fact, occurring we are losing information, because the maximum NDVI values are obtained under the periods/week/months where precipitation is none stop. Of course, this is an acceptable loss, because the presence of water in clouds would affect negatively the NDVI. Additionally, the use of mean NDVI allowed us to eliminate the possibility of the NDVI value obtained to be the result of some punctual event, or due to the lack of monthly samples.

With this analyzes we can undertake that in our study areas, the data showed no great differences in vegetation density, to state that biodiverse pastures have a larger primary net productivity, when compared with the natural pastures of the same study areas. Furthermore, it is not possible to correctly state that these pastures would be a suitable adaptation measure to the seasonal changes in precipitation patterns of the Mediterranean ecosystems.

4.2. Study areas and Type of Soils

We studied if with the implementation of the biodiverse pastures, an actual increase of density was observed in farms. Our results show that only 28/50 had an actual increase of density, being the rest unaltered or with a reduction in density. It would be expected the biodiverse having higher ratios, demonstrating its ability of improving vegetation density and, productivity.

The overall ratio comparison between the biodiverse and the previous showed no differences in density, which means, the implementation of the biodiverse pastures did not change the vegetation density of the farms, as it would be expected.

Comparing the pastures in a local scale showed some noticeable differences. The density of biodiverse pastures was higher than the previous pastures in Mértola, and lower in Beja. This means, Mértola had an increase of vegetation density with the implementation of the biodiverse pastures, and in Beja a reduction. We were expecting the biodiverse ratios having the higher ratio, as a reflection of these pastures high productive rate (Crespo, 2008; Teixeira *et al.*, 2010; Teixeira *et al.*, 2015). As in comparison with peripheric natural pastures, the vegetation density differences were very small or nearly absent, which means that both pastures had similar densities, and, as consequences similar productivities.

The study areas exist in the same climatic region, meaning that they are under the same climatic conditions and variations, varying only in soil characteristics, and eventually slope, terrain orientation and grazing regimes.

One explanation for the local differences could related to problems during the installation process. According with the guide of Compromises and Recommendations of Pastures management (*Terraprima*, 2009), for the installation of the biodiverse pastures to be correctly done, the farmers need to fulfill the following steps:

- The seed mixture as to be the correct one for the edaphoclimatic characteristics;
- The terrain as to be clean of all organic matter (vegetable residues and shrubs) and firm and flat;
- The sowing as to be done in the beginning of September, never before October, in order to benefit with good soil temperature conditions and optimal sunlight;
- The soil depth needs have at maximum 1.0 and 0.5 cm at minimum, being an important factor in the installation process;
- The scrolling process is very important, because for the seeds to successfully germinate, they must be well compacted in the soil;
- In soils with the deficiency on certain nutrients, it is necessary the application of some correctives or fertilizers (like phosphor, potassium, etc., depending of the kind of deficiency).

Differences in farmer´s land management, type of cattle grazing and intensity of grazing also have an important effect on pastures productivity. The guide of Compromises and Recommendations of Pastures management states that in the first year of implementation:

- The seed bank must be rich in species and varieties, so a good management is the difference between success and failure. So, sowing must be done in a warm and well fertilized soil;
- The grazing during the period of Autumn/Winter must take into account the field conditions, and can never be done before the plants achieve the 5 to 7 leaves;

- The Autumn/Winter grazing focuses in infesting weed control, using high animal load (40-50 ovines and 5-8 bovines) during periods of 3 to 5 days. The repetition of this process can be made one to two times between intervals of 30 of 40 days;
- The grazing is forbidden after the emergence of the first flowers, normally at the end of February, allowing a non-stressful growth and a higher production of seeds;
- The grazing process restarts only after the drying of all the plants, a phenomenon that usually starts in June. This process will allow the consumption of all the dry organic matter, and facilitates the emergence of new plants, before the first Autumns rain (*Terraprima,* 2009).

After the first year, the grazing can be done continuously or in rotations, only after the first rains of October and 2/3 weeks of non-grazing activities in the pastures. It is important to prevent over grazing during consecutive years, the dry pastures have to be well removed before the first Autumn rains, and the soil have to fertilized in accordance with its deficiencies in nutrients (*Terraprima,* 2009).

In the first and second year of implementation the biodiverse pastures had higher vegetation densities, when compared with the average pastures that existed previously, and in the third year the densities where lower. The three-year implementation may not be enough time to obtain the expected results, so we can state that in a short term the implementation of biodiverse pastures does not greatly improve the system´s productivity.

We identified three major soils study areas: Eutric Lithosols, Eutric Cambisols (sedimentary rocks post-Paleozoic) and Luvisols. The Cambisols only existed in Beja and the Lithosols in Mértola; the Luvisols existed in both sites. The pastures existing in the Lithosols had the very similar densities; in the Luvisols, we found the biodiverse pastures were denser than the previous pastures; and when we analyzed the Cambisols, showed us a larger density in previous pastures than in the biodiverse pastures. Furthermore, comparing the three years of implementation of the biodiverse pastures, it was very apparent that the Lithosols and Luvisols had, seemingly, the highest densities, with the second year having the highest values. Once again, the Cambisols had slowest vegetation density, rising very modestly across the years and the productivity was always low.

One major observation we can undertake in the local and soil pastures comparison is, in fact, if we only consider the local differences between the pastures, it is very apparent the absence of significant differences, but if we separate the locals in different soils, the differences in productivity becomes more clear. The Luvisols and Lithosols had clearly the highest ratios in the three implementation years, showing that these soils were the better soils. We need to take in mind the fact that some samples are very low, meaning that there is a high probability that some values are under evaluated, especially in the third year.

As some studies state, the biodiverse pastures have the capacity of increasing the systems nitrogen supply, reducing the need for fertilizers, and organic matter reservoir, allowing a better condition for vegetation growth (Crespo, 2015; Teixeira *et al.*, 2015). It should expectable a large increase in productivity in each soil, but the data shows differential productivity rate between these soils.

These results may be an explanation for why the local comparison of the previous and biodiverse pastures were considerably different. The Cambisols only existed in Beja, and the previous pastures had higher NDVI ratios in these soils, so this result was reflected in the local comparison between the pastures (Figure 3.5). Additionally, the lithosols can also be found in Beja, and as seen in Figure 3.6 these soils had higher previous NDVI ratios, which, also, got reflected in the local pasture comparison analyses. The soils with the higher biodiverse pastures ratios existed in Mértola, which could explain why the vegetation density in the biodiverse pastures where higher in this location.

The three soils are very productive in different soil uses; the Eutric Cambisols and Luvisols have a high aptitude for agriculture use; and the Eutric Lithosols are more suitable for forestry and a potential resource for grazing (Soil Atlas of Europe, 2005; Tóth *et al.*, 2008). So, the high density found in the biodiverse pastures was expected, despite the difference not being very high once compared with the natural pastures and previous pastures.

The Cambisols are characterized by having a medium textured, a high porosity, a good structural stability, good internal drainage, a good water holding capacity, and active soil fauna. Furthermore, they possess a neutral to weakly acid soil reaction, and a satisfactory chemical fertility. These characteristics combine allow it to be a very productive soil, and a good agriculture land (IUSS, 2015). We hypothesize that the lack of differences in productivity between the natural pastures, the biodiverse pasture and the previous pastures can be related with the absence of limitations to vegetative growth found in the Cambisols. Seeing that, the Cambisols are very fertile and well suited for agriculture practices, it is expected similar growth rates in each pasture, which explains the similarity in NDVI with the natural pastures. The high ratio found in the previous pastures maybe a reflection

The Luvisols are porous, and well aerated and drained, but very poor in organic matter and a small ratio of C/N (10 to 15). The surface is completely or partly de-calcified and slightly acid (IUSS, 2015). These characteristics made the soils very limiting the pastures growth, explaining why the natural pastures and the previous pastures productivity was low. The implementation of the biodiverse pastures, clearly helped improved the productivity in this soil. The increase of organic matter, N in the soil and P by fertilization, allowed the biodiverse pastures to be very productive, under growth limited conditions.

The Lithosols have a good drainage, but a low water holding capacity that, in addition to its shallowness and/or stoniness surface characteristics, makes this soil very limiting to growth (IUSS, 2015). This fact, may explain the low productivity seen in both pastures. The low productivity of the biodiverse pastures, when compared with the previous pastures, may be related to the fact that legumes are unable to fixate N because in water stress conditions. The water stress conditions disrupt the interactions between Rhizobium and the host plant, altering nodule fine-structure, which leads to the decreases nitrogen fixation and the growth of the legumes (Dejong & Phillips, 1982). So, the biodiverse pastures probably became limited in nitrogen resource, which consequently led to low grass production, explaining the low ratios obtained in this soil.

According with Flynn (2006), it is important to consider the effects of soil characteristics in the NDVI results. Characteristics, like soil type, texture, moisture content, presence of organic matter, color, and the presence of iron oxides, have considerable effects on RED and NIR radiation absorbance, affecting the NDVI obtained. In this case, field samples would have been important to calibrate some of the values obtained. It is important to state that we, also, did not consider the soil moisture in this study. This variable is well known to influence vegetation patterns (Diodato and Bellochi, 2007), and it is important to be considered in future studies.

4.3. Bioclimatic variables

4.3.1. Precipitation

In semi-arid and arid ecosystems, precipitation is an important factor, affecting the vegetation´s growth and overall productivity (Ding, 2012; Cramer & Hoffman, 2015).

According with Figure 3.9, 2010 and 2011 were the wettest years in all the 8 years. This means that the precipitation in those years was higher than the average, this information is reinforced with the annual precipitation graphics (Figure 7.1). The years that registered the lowest precipitation anomaly were identified has the driest years, which, in this case, were 2007 and 2012.

As expected, the driest years registered low vegetation densities from biodiverse and previous pastures, since drought events impact negatively the grassland´s productivity and net ecosystem carbon exchange (Jongen *et al.*, 2011); but, when comparing the pastures, we expected a higher density from the biodiverse pastures. Some compositions of biodiverse mixture contain drought resistant perennials with deep roots (e.g. *Trifolium fragiferum, Onobrychis viciifolia, Hedysarum coronarium* and *Medicago sativa*) and summer dormant species (e.g. *Dactylis glomerata, Phalaris aquatica, Festuca arundinacea* and *Lolium perenne*) (Teixeira *et al.*, 2015), which concedes the biodiverse pastures the capacity to withstand, more efficiently, water-limited stresses, like long periods of drought. Our expectation was not observed, instead the previous pastures had the highest, meaning that their density was higher than the biodiverse pastures.

As for the wet years, we were expecting high densities from both pastures, with the biodiverse pastures registering the highest values, due to its capacity use more efficiently rain water (Teixeira *et al.*, 2008a; Rodrigues, 2008; Teixeira *et al.*, 2015). Our expectations, in fact, were observed, the higher vegetation density was registered in the biodiverse pastures.

Variations in precipitation events, amount, intervals, and timing, can affect the productivity and respiration of grasslands (Jongen *et al.*, 2011). An extend of precipitation events, especially during late spring and summer time, allow the soil to have a high soil moisture rate in the stressful periods (Aires *et al.*, 2008). The Table 7.1, shows the occurrence of rainy events during summer time in Beja, during 2007, which could be an explanation for why the vegetation density of previous pastures was higher than the biodiverse pastures. The biodiverse pastures samples for the dry years, were from 2012, a year where the precipitation was very scarce, lower than 2007, with absence of precipitation between June and October. So, the low ratios obtained for the biodiverse pastures, could be the reflection of the high variability of precipitation found in that year (Figure 7.1).

The two wet years chosen for our study, had wet summers (Table.7.1) and high precipitation seasonality (Figure 7.1) which means that these years had monthly more precipitation than normal, leading to an extend of the growing process into the hotter months. The biodiverse pastures have a greater efficiency in rain water use, this may be an important factor in the differences of densities between the two pastures, because it allows the increase of soil moisture, and the availability of water in ecosystem characterized by low precipitation and periods of extended drought.

We assumed, with this study, the precipitation variation through the years would be reflected in variations in NDVI ratio rate, but, as stated in Diodato & Bellochi (2007), this only would make sense in moderate water holding soils, something we did not take in account.

Our study only focused on the annual amount of precipitation and its influence on the pastures, neglecting the effect of changes precipitation patterns. It is known that changes in normal precipitation patterns can affect largely a community composition, which, consequently, may impact the structure and function of an ecosystem (Huxman *et al.*, 2004). So, some of the results may reflect some of these changers.

The data emphasis that the implementation of the biodiverse pastures would not be the best solution to enhance the Portuguese Montado resilience in case of drought events. In the contrary, in a dry year, this option would be a less positive option, since the previous pastures had the higher ratios, reflecting in a higher vegetation density, when compared with the alternative, the biodiverse pastures. The ratios reflected, also, the weak differences with natural pastures, seeing the values were not greater than 1. Considering the wet years, we can assume that the biodiverse pastures would probably be a better option, seeing that would allow the farmers a greater use of the excess amount of precipitation that can occur in wet years.

4.4. Management and Conservation

Our results clearly demonstrated that, in this particular case, the implementation of sown biodiverse permanent pastures rich in legumes did not have a higher productivity in the drier years, compared with the natural pastures. In soils with low water holding capacity, like the Lithosols, these pastures showed lower vegetation densities, when, once again, compared with the grasslands that exist in the study areas. In soils with organic matter and nitrogen deficiency, namely the Luvisols, the implementation of the biodiverse pastures improved the productivity of the system. The Cambisols, a type of soil with no limitation on vegetative growth, showed a better productivity from the previous pastures, when compared with the biodiverse pastures.

Despite our results not showing improvements in productivity in the ecosystem, we consider the SBPPRL to, still, be an important option to improve the ecosystem´s quality. The application of the Normalized Difference Vegetation Index is not sufficient to withdraw strong conclusions about quality environment. According with Diodato *&* Bellochi (2006), plants are important regulators of water, carbon and energy exchange in the ecosystem, so we can take some interpretations about changes in ecosystem quality with the changes in vegetation cover. But, the complementation with field work is very important in future studies, allowing the comprehension of the why and the consequences of those changes. Hence, we consider that field analyses (e.g. soil moisture, texture, root density, fauna) and interviews with the farmers would have complemented in a very positive way the interpretation of our results.

For example, soil is a very important component of the ecosystem, providing water and nutrients for plant growth (Esteves, 2013), and the structure of the different vegetation communities are strongly dependent on soil physical characteristics and moisture (Diodato *&* Bellochi, 2006). So, by analyzing the differences of soil water holding capacity, some vegetation density found would probably be explained differences in soil moisture in the different soils. Water availability strongly affects plant productivity.

Studies carried out by Crespo (2008), Rodrigues (2008), and Teixeira *et al.* (2008, 2011, 2015), clearly demonstrate that these bio-engineered pastures have very positive effects on ecosystem organic matter content, fertilization, water use and storage efficiency, and cattle feeding.

The ability to capture great amounts of atmospheric CO_2 (± 4.7 ton CO_2/year/ha) (Rodrigues, 2008), and to fixate the atmospheric N (thanks to its richness in legumes) in the soils, concede a more nutrient rich environment, allowing the grass to have a higher quality and production in a very low cost (Crespo, 2008), and making the cattle feed more nutritious. The increase of available nutrients also improves the soil fertility, quality, and resilience, reducing its vulnerability to erosion. In water-limited environment, like the semiarid dryland, the increase of soil´s organic matter allows a better water retention, reducing consequently, the amount of water loss, the contamination by pesticides, eutrophication, water sedimentation, and the erosion caused by surface runoff (Teixeira *et al.*, 2008b; Rodrigues, 2008; Teixeira *et al.*, 2015). As a carbon sink, these pastures have a great importance in reducing the atmospheric CO_2. By increasing the amount of water available for the system, these pastures may allow a higher accumulation of organic matter, better distribution of the nutrients through the soil (nutrient mobility in soils is also determined by water availability) and the increase of microbial flora (Cramer & Hoffman, 2015). Furthermore, these pastures have very positive effects on microorganisms, little arthropods, coprophages insects and earth worms, supplying food and a more favorable environment for their development (Teixeira *et al.*, 2008b).

The increasing carbon sink, water storage capacity, and productivity of a system is the main goal of some adaptation measures. Though, the biodiverse pastures have proven to, in fact, fill these categories, our study demonstrated that in water stress environments (e.g. low precipitation and bad soil water holding capacity) these pastures become very limited in productivity, which means that, in these conditions, their adaptation capacity becomes, also, very limited. We need to take in mind, that assessments in increase and reduction of carbon fluxes in the system based on growth measurements are very limited, due to the fact they only consider aboveground and tree increase of biomass, ignoring root density increase (Arneth *et al.*, 1998). Hence, despite the aboveground biomass not registering increases of biomass, the underground can, in fact, have increased in density.

Taking into to account our results, we consider that the implementation of biodiverse pastures as an adaptation measure should only be an option for soils with deficiencies in organic matter and nitrogen, and good water holding capacity, in order to enable legumes growth and nitrogen fixation.

Focusing on biodiversity conservation, as suggested by Vos *et al.* (2008) and Stein *et al.* (2013), we propose that future adaptation strategies should be multi-faceted, focusing on the increasing of the ecosystem connectivity and the area of ecosystem networks (especially in regions with low and widely distributed dispersal sources); create additional protected areas for species, especially the more vulnerable; and protect climate refugia sites. Hence, we consider that future studies on biodiverse pastures as adaptation measure should consider these strategies.

Chapter 5 - Final Considerations

In this dissertation, we wanted to study the adaptive efficiency of the sown biodiverse permanent pastures rich in legumes, in climate change like conditions. Our results showed no significant differences in vegetation density between the biodiverse pastures, when compared with natural grasslands/natural pastures from the study areas. Separating the pastures in different soils, the differences become more apparent. The biodiverse pasture had smaller density in Cambisols once compared with previous pastures, and the differences with natural pastures were slim to none. The previous and biodiverse pastures in the Lithosols had lower productivities, when compared with the natural pastures, meaning the implementation of the biodiverse pastures had not improved the farmer's productivity in these two soils. Finally, the Luvisols had the higher densities, and the most noticeable differences between biodiverse and previous, with the first one being more productive than the second one. The biodiverse productivities were higher than the natural pastures. In drought conditions, more specifically in dry years, the biodiverse pastures did not show the high productivity that was expected. In such manner, we can, modestly, say that, in these two specific regions, the natural grasslands are more productive that the biodiverse pastures and, under periods of water scarce, these pastures are better adapted and more productive.

In our study, we only considered annual precipitation. In our view, a study more focused on the effects of different precipitation patterns on the biodiverse pastures and natural pastures, would highlight the differences in respiration and photosynthesis. If a more robust analyze would be conducted to observe the monthly NDVI variations, to study this influence, we recommend the usage of Satellites that allow the attainment of a large number images replicates for each month (e.g. MODIS[2]).

Our analyses focused only in a quantitative perspective, by using the Normalized Difference Vegetation Index (NDVI) as quantification measure of differences between the studied pastures. A quality perspective could have been very beneficial to the study at hand, and is our desire that future studies on the same thematic would also focus on quality improvement, when comparing these pastures.

Furthermore, we want to emphasize the importance of considering the feedback from the farmers as complement for future studies. Hence, individual interviews with the farmers that implemented and/or are implementing the biodiverse pastures should be addressed in those futures studies. The interviews would allow the comprehension of the main problems, if any, with the usage of the biodiverse pastures; what type of management was carried out by the farmers, outside the recommended by *Terraprima*; and the effects of the different types of cattle used in the grazing.

[2] For more information, visit the official site: https://modis.gsfc.nasa.gov/

Chapter 6 – References

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Chapter 7 - Annexes

I: Annual Precipitation and Precipitation Seasonality

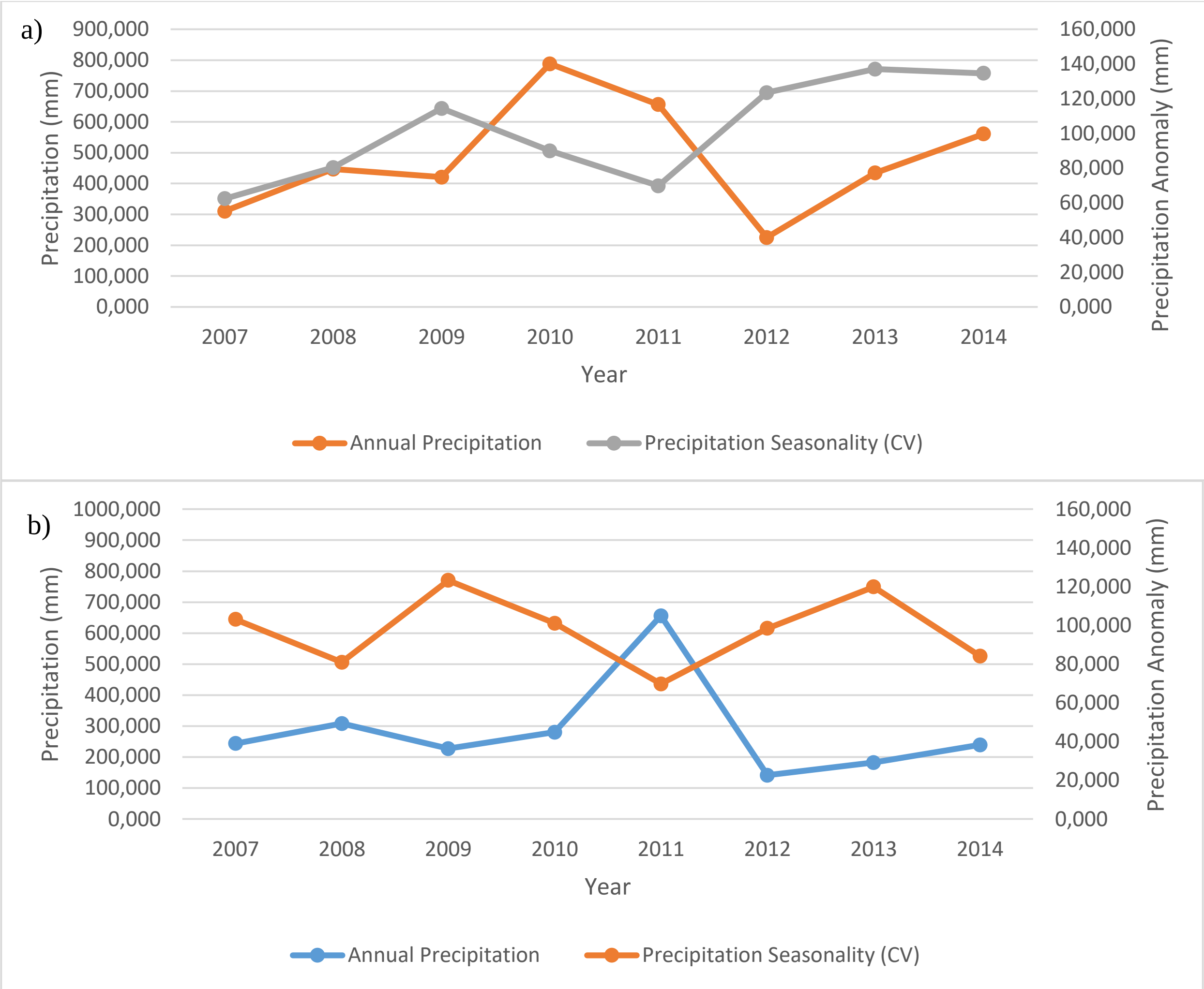

Figure 7.1 - Annual Precipitation and Precipitation Seasonality for a) Beja and b) Mértola.

II: Monthly precipitation variation

Table 7.1 - Monthly Precipitation of Beja and Mértola.

Local	Months	2007	2008	2009	2010	2011	2012	2013	2014	Monthly precipitation (2007-2014)
Beja	January	20.10	32.10	71.40	64.10	40.20	17.50	61.50	0.00	38.4
	February	54.50	98.70	45.90	159.90	43.30	0.80	41.50	8.70	56.7
	March	11.50	16.60	6.50	79.80	79.30	54.90	173.50	38.40	57.6
	April	30.50	53.00	38.10	91.00	107.00	57.50	25.20	89.40	61.5
	May	52.50	67.80	4.00	26.70	53.10	39.60	12.90	11.90	33.6
	June	31.50	0.40	6.20	17.00	50.50	0.00	4.50	21.90	16.5
	July	0.00	0.00	0.10	0.00	0.00	0.00	0.00	7.00	0.9
	August	12.70	0.10	0.00	0.00	10.90	0.00	2.40	0.10	3.3
	September	41.00	38.60	25.60	4.10	66.50	0.00	17.40	54.30	30.9
	October	23.50	39.90	57.20	99.20	63.00	0.00	86.60	85.40	56.9
	November	15.00	33.80	23.40	69.10	131.30	4.20	6.50	225.60	63.6

	December	17.40	65.70	142.20	177.10	10.90	50.70	2.20	18.10	60.5
	Mean	**310.20**	**446.70**	**420.60**	**788.00**	**656.00**	**225.20**	**434.20**	**560.80**	**480.213**
	January	0.00	41.60	4.10	10.90	56.40	8.70	31.90	30.60	23.0
	February	0.00	48.10	33.00	52.70	54.70	1.00	37.60	22.70	31.2
	March	8.60	6.40	5.60	25.80	117.00	9.10	63.20	8.60	30.5
	April	62.30	49.90	4.30	33.90	95.00	39.60	14.90	34.60	41.8
	May	8.00	24.10	61.80	6.30	60.50	28.40	8.50	0.00	24.7
	June	0.00	0.00	5.50	17.50	4.50	0.10	1.50	55.20	10.5
Mértola	July	0.00	1.40	0.40	0.20	0.00	0.00	0.00	4.40	0.8
	August	14.90	0.00	0.00	3.80	12.20	0.00	0.00	0.00	3.9
	September	47.90	49.80	9.10	8.40	15.30	7.60	11.40	24.10	21.7
	October	35.40	52.80	73.30	29.90	88.10	8.50	1.20	37.40	40.8
	November	44.80	21.90	10.00	6.40	42.20	21.40	3.70	20.70	21.4
	December	22.10	12.20	20.50	84.60	5.30	17.10	8.80	1.10	21.5
	Mean	**244.00**	**308.20**	**227.60**	**280.40**	**551.20**	**141.50**	**182.70**	**239.40**	**271.875**

III: Average temperature from 1981 to 2010

Table 7.2 - Mean, maximum, and minimum monthly temperature (1981-2010).

Months	Mean Temperature 1981-2010 (ºc)	Max Temperature 1981-2010 (ºc)	Min Temperature 1981-2010 (ºc)
January	9,7	14	5,4
February	10,8	15,5	6
March	13,4	19	7,7
April	14,6	20,4	8,7
May	17,7	24,3	11
June	22	29,9	14
July	24,6	33,3	15,8
August	24,8	33,1	16,4
September	22,4	29,4	15,4
October	18,2	23,5	12,9
November	13,6	18	9,2
December	10,7	14,5	6,8

IV: Temperature and Temperature Anomaly between 2007 and 2014

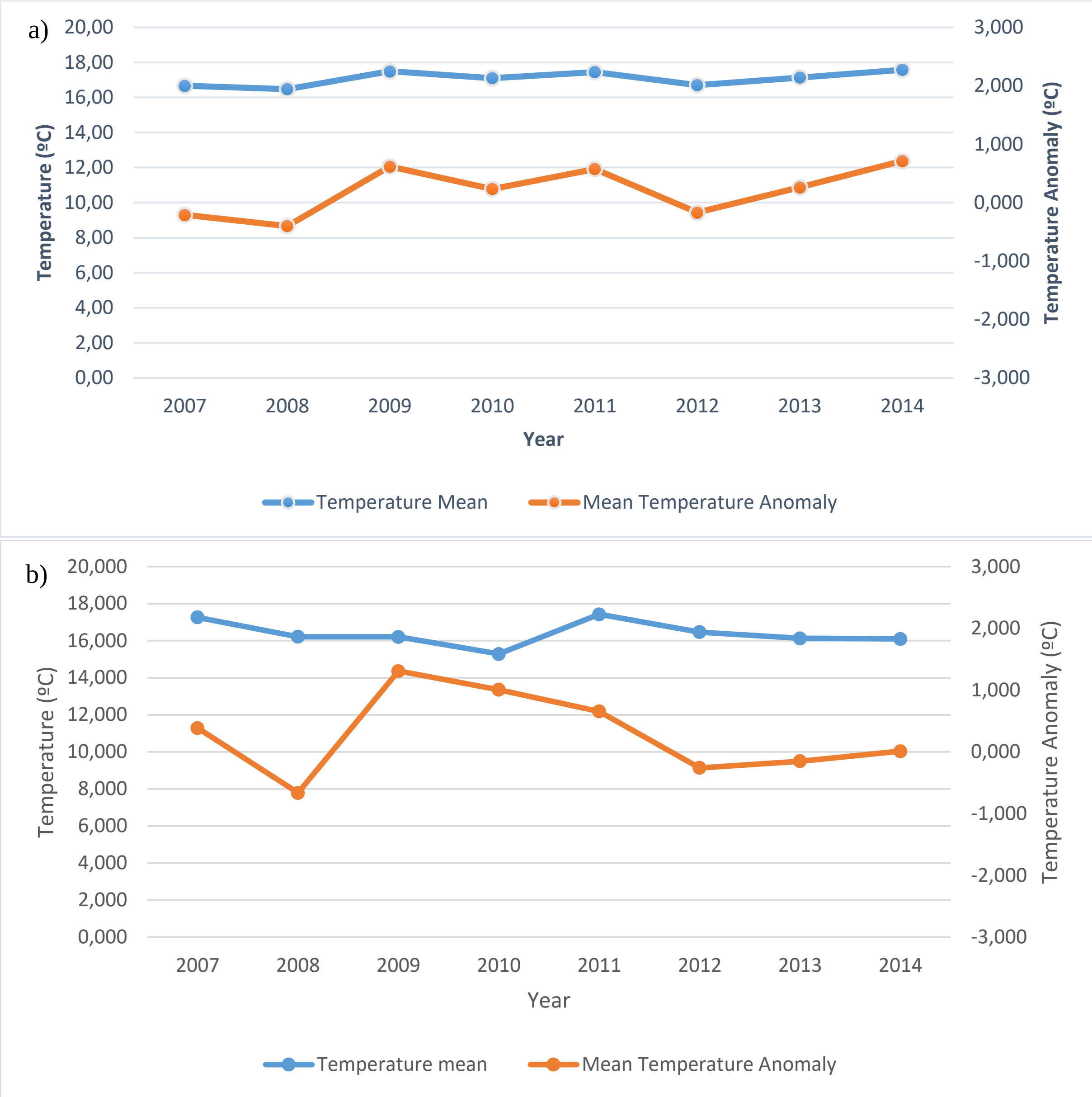

Figure 7.2 - Temperature mean and Temperature mean anomaly for a) Beja and b) Mértola.

V: Dry and Wet years with the precipitation anomaly varying between -50 and 50 mm

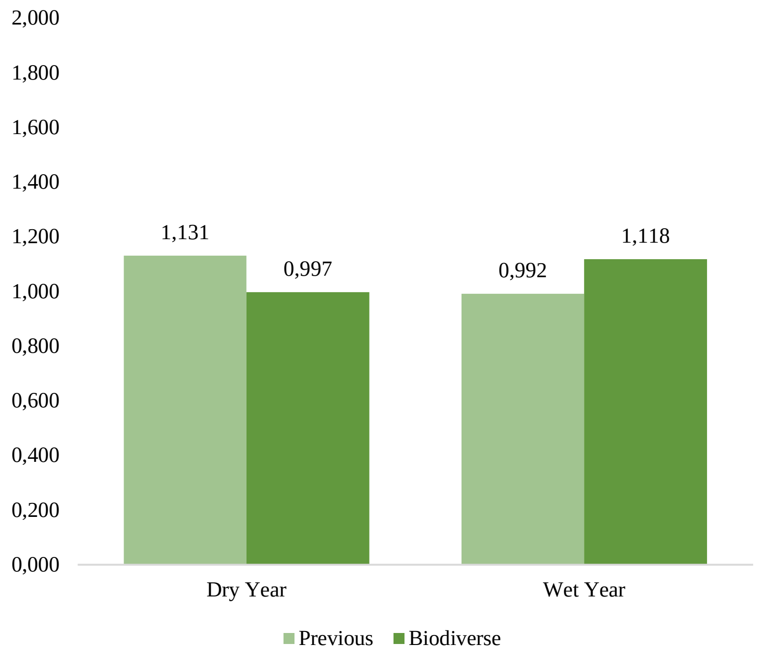

Figure 7.3 - Pastures comparison between Dry and Wet years.

VI: Number of months used and Missing months

Table 7.3 - Months used in the analyses

YEARS	NUMBER OF MONTHS USED	MISSING MONTHS
2014	8	February, June, July and December
2013	10	February and January
2012	5	December, November, June, May, April, March and January
2011	8	December, September, August and February
2010	8	December, September, February and January
2009	8	December, June, May and April
2008	4	October, September, June, July, May, March, February and January
2007	8	September, April, March and February